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A VLF-LF RECEIVER - 10kHz TO 500 kHz WITH RESISTANCE TUNING

LLOYD BUTLER VK5BR
18 OTTAWA AVE, PANORAMA 5041

Introduction

Few communications receivers tune to frequencies below 500 kHz and because of this, many radio enthusiasts are unfamiliar with this section of the radio frequency spectrum which supports numerous radio services.

Likewise, the writer had no receiver which could tune these frequencies and set out to design a simple receiver for just that purpose. The superheterodyne receiver described is the result. It has been designated a VLF-LF receiver, because it tunes the VLF-LF range from 10 to 300 kHz, but it also tunes part of the MF spectrum from 300 to 500 kHz. The VLF and LF bands have their own unique useful characteristics and these will be discussed further on.

The receiver design is a little different from the usual form. It has no variable capacitors or inductors except for one preset trimmer in a trap circuit. Tuning is carried out by a potentiometer, the resistance of which sets the frequency of the heterodyne oscillator. The RF end is untuned and the receiver bandwidth is set by two inexpensive ceramic filters in the IF channel. All inductive elements are provided by stock lines of miniature RF chokes.

Because of the low frequencies involved, it has been possible to use a number of excellent integrated circuit packages which would be unsuitable on the HF bands. The circuit diagram of the receiver is shown in figure 1 and the following discussion refers to elements in that diagram.

The Mixer Stage

The mixing is carried out by an operational multiplier package type XR2208. This device is suitable for use at frequencies up to 8 MHz, and as a mixer at low frequencies its performance is outstanding. Performance tests at an input frequency of 200 kHz and an intermediate frequency (IF) of 455 kHz have produced the following results:

Conversion gain (Ratio of output level at 455 kHz to input level at 200 kHz): minus 6 dB.

Equivalent noise level at input: 10 microvolts in a 1 kHz band.

Third order intermodulation products: At input levels below 70 microvolts, products are below the noise floor. Even at 1 volt input, the third order products are 55 dB below signal level at 455 kHz.

Level of signal at the output, equal in frequency to the input signal: 33 dB below the level at the input.

Level of signal at the output, equal in frequency to the local oscillator frequency: 53 dB below the level of the oscillator at the mixer input.

The low level of third order intermodulation products adds up to a low order of nuisance intermodulation beats or "birdies". The low level of local oscillator signal in the output assists in achieving operation with the oscillator frequency close to the intermediate frequency, as is needed when tuning at signal frequencies down to 10 kHz.

The Tunable Local Oscillator

For a tunable oscillator, precision oscillator package type XR2209 was selected so that variable resistance tuning could be applied. This device can be operated at frequencies up to 1 MHz and for an R-C tuned oscillator, has the excellent temperature stability of 20 parts per million per degree Celsius. For the maximum oscillator frequency of 955 kHz required, frequency drift over a 20 degrees change is therefore only 360 Hz.

The XR2209 can be connected for either square wave or triangular wave output, the latter of which is fed to the mixer via a sine shaping filter. The filter is used to reduce the possibility of oscillator harmonics mixing with high level high frequency signals, which manage to get through the RF filter at the receiver input and produce unwanted IF beats.

The tuning is carried out by two potentiometers, one for coarse tuning and one for fine tuning. The fixed tuning capacitance and the limiting resistance in series with the two potentiometers, are trimmed to obtain an oscillator frequency range of 465 to 955 kHz, which is 455 kHz higher than the tuning range of 10 to 500 kHz. The coarse tuning potentiometer is connected to a dial which is calibrated in coarse frequency. The values of resistance and capacitance have been selected to suit the full resistance range of the coarse potentiometer. If a vernier dial is used with a shaft rotation of only 180 degrees, the value of limiting resistance can be decreased and the value of fixed capacitance increased to correct for this.

RF & IF Amplifcation

To provide RF and IF gain, JFET operational amplifier packages type LF353 have been used. These are an 8 pin DIL package containing two amplifiers with a 4 MHz gain-bandwidth product. At the frequencies involved, a gain of 100 for each package. The RF amplifiers are actually set to realise a gain at low frequencies of 20 per unit, giving a total gain of 400. Of course, this gain decreases at the high frequency end of the tuning range.

One LF353 package is used for RF amplification and one and a half LF353 for IF amplification. The remaining odd half is used as an audio driver following detection.

The RF Circuit

The front end of the receiver is broadbanded up to a frequency of around 500 kHz above which higher frequencies are attenuated by a low pass filter. The function of the low pass filter is to reject signals at image frequency which, as it happens, fall within the broadcast band. It also rejects higher frequency signals which could mix with harmonics of the local oscillator to produce a 455 kHz IF

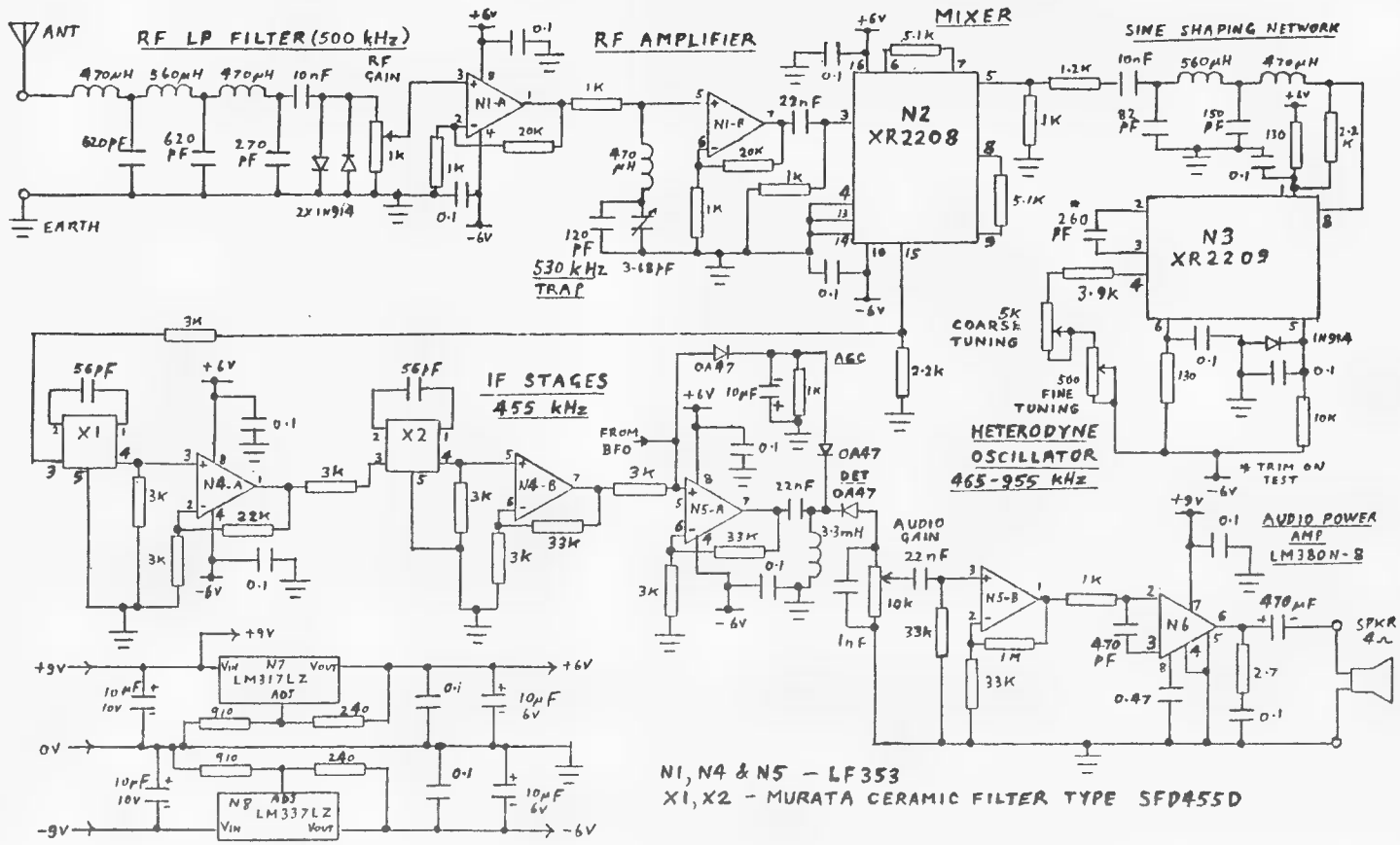

Figure 1 VK5BR VLF-LF Receiver Circuit Diagram (Refer also to fig 4 for BFO)

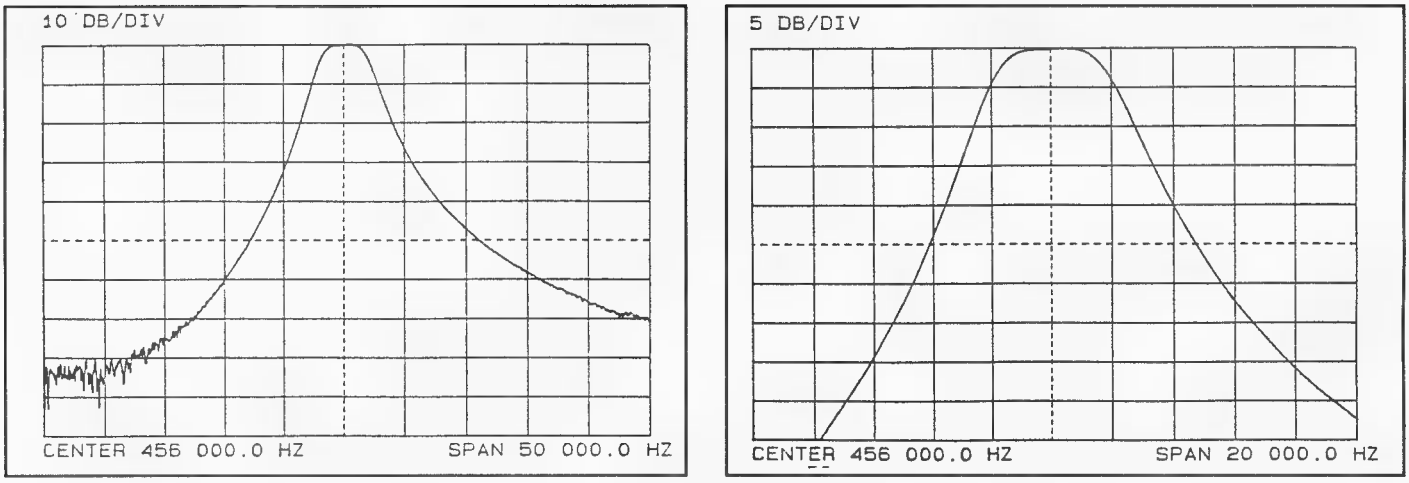

Figure 2 Intermediate Frequency (IF) Response

beat. The 3 dB cut off point of the filter is set at 500 kHz and its response is 55 dB down at the 2nd harmonic of the cut off frequency.

In the coupling circuit between the two RF amplifier stages, a trap circuit is also included. In the first instance, the receiver was made to reject signals above 420 kHz and the trap was fitted to reject direct signal pick up at the intermediate frequency. Direct pick up at 455 kHz proved to be no problem and this was attributed to the properties of the XR2208 which balance out the input signals. Furthermore, the receiver could also be tuned across 455 kHz with no undesirable effects. In consequence of this, the input filter was changed for a cutoff frequency of 500 kHz to extent the range of the receiver. The only problem with this change was that it opened up the RF end to signal entry at the extreme end of the broadcast band. Strong local station 5UV on 530 kHz mixed with the second harmonic of the heterodyne oscillator to produce a signal when the receiver was tuned to receive 37.5 kHz. Furthermore, if the RF gain was set too high, 5UV would cross modulate other signals. To eliminate this problem, the trap was set to the 5UV frequency just above 500 kHz.

The IF Circuit

The selectivity of the receiver is achieved with two Murata type SFD455D ceramic filters in the IF channel. These are a low price unit essentially made to replace 455 kHz IF transformers in transistor receivers. Using the two of these filters, the 3 dB bandwidth is 3.7 kHz and adjacent channel rejection is 47 dB at 10 kHz from centre frequency and 65 dB at 20 kHz from centre frequency. The response of the IF channel is shown in figures 2a & 2b. Figure 2b is an expanded version of 2a. The steep slope of the IF response enables signal reception down to 10 kHz. For this tuned condition, the heterodyne oscillator runs at 465 kHz and this must be rejected by the IF channel.

The values of components connected around the filters are as suggested in the manufacturers brochure but if a wider bandwidth is desired, it can be achieved by a change in these values. The writer experimented with one of these filters and found that its bandwidth could be expanded to around 7 kHz by operating with the circuit constants shown in figure 3.

Audio Stages

The IF signal is detected by a diode and following R-C filter. The audio output is fed via the half LF353 pre-amplifier to an 8 pin version of the LM380 power amplifier. The LM380 has internal thermal limiting and using heat sinking only via the circuit board pins, it can deliver an audio power of up to 1 watt into a 4 ohm load with a power supply of 9 volts.

Beat Frequency Oscillator (BFO)

Most of the signals heard within the frequency range transmit in the AM or MCW mode and the receiver was initially wired up for only that type of reception. However, there are also CW signals on the bands, such as those transmitted by the marine coastal radio, for which a BFO is needed. A BFO is also useful for detecting the presence of some of the navigational signals such as Omega. A BFO was eventually added and this is shown in an additional diagram, figure 4.

The 455 kHz ceramic filters, used in the IF stages, are quite inexpensive and this provided an attraction to use a third filter for crystal control of a stable BFO. Tests on the filter showed that a crystal element could be accessed between pin 5 and any of the other pins on the filter and each element gave a parallel resonance around 456.85 kHz. Pins 1 and 2 elements were found to produce a higher Q than pins 3 or 4 elements.

Another half LF353 was pressed into service to form the oscillator in conjunction with the ceramic element across pins 1 & 5 and other components as shown in figure 4. Frequency of oscillation was measured to be 456.36 kHz, which was a satisfactory offset to 455 kHz to operate the incoming signal within the 3.7 kHz IF passband and give a suitable audio frequency beat. The series inductor and shunt capacitor at the amplifier output form a sine shaping filter fitted as a precaution in case harmonics of the BFO caused any problems. The second buffer amplifier is really unnecessary, but it was given a job to do, as it was available as a spare in the LF353 package and required no extra components.

The component values shown to make the circuit oscillate were determined experimentally on a single LF353 and a

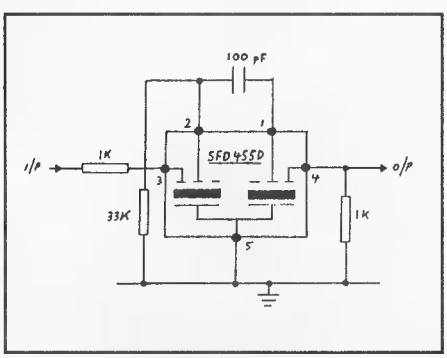

Figure 3 Ceramic Filter - Connection for wider bandwidth

single ceramic filter. This is pointed out because, in duplicating the circuit, constants in these devices (particularly the filter) might well vary in different samples, possibly resulting in the need for a change of component values in the feedback path.

Power Rails

Split power rails of plus and minus 6 volts are used for all stages except the audio power amplifier. The split rails enable precise centring of amplifier operating points making it easy to directly couple, without capacitors, many of the amplifier stages. The 6 volt rails are derived by voltage regulators type LM317LZ and LM337LZ from a nominal source of plus and minus 9 volts. These regulators are packaged in standard TO-92 transistor cases and are very compact. The regulators are needed to stabilise the voltage, in particular to the XR2208 oscillator, as its high frequency stability can only be achieved if its power rail voltages are held constant.

Decoupling of the 6V rails is used in feeding both oscillator circuits. These are running at a high signal level and the decoupling is necessary to prevent coupling into other circuits via the power rails.

The audio power amplifier is powered directly from the positive 9 volt source and does not load the regulator.

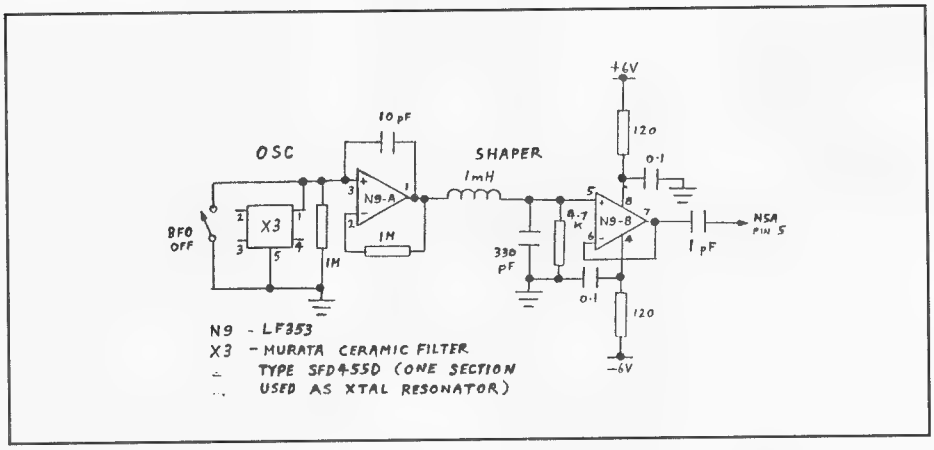

Figure 4 Beat Frequency oscillator (BFO) Circuit Diagram

The regulated load current is approximately 30 mA per 6 volt rail and is well within the 100 mA capacity of the regulators. The additional load current from the LM380 increases the current on the 9 volt positive supply to 37 mA in the quiescent state and to 134 mA when the power amplifier is driven to its maximum output with continuous sine wave wave signal. Under signal conditions, average current is in the order of 50 mA.

The 9 volt power sources can be two small 216 type torch batteries or twin unregulated DC supplies rectified from a transformed AC supply. If batteries are used, the positive supply must be shunted with a 2200 µF electrolytic capacitor to prevent the swinging load current of the LM380 from developing a corresponding voltage drop across the battery internal resistance. If the voltage is allowed to swing below 7.7 volts, the regulators cannot do their job and instability occurs. This also puts a limit on how far the batteries can be discharged before the regulated voltage fails. The possibility of instability is eliminated if a separate (third) battery is used for the LM380 so that supply to the regulators is unaffected by the LM380 varying load.

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Overall Sensitivity

For satisfactory performance, receiver generated noise level, referred to the receiver input, must be lower than the noise incoming from the antenna. At low radio frequencies, the atmospheric noise is very high and hence receiver sensitivity does not have to be as good as that normally sought for receivers operating in the HF or VHF bands. In this receiver, the minimum discernible signal level is around 3 microvolts for frequencies below 100 kHz. Above 100 kHz, sensitivity falls because of the shaped response caused by the RF filter and the 530 kHz trap and to a lesser extent by the failing response of the RF amplifiers at high frequencies. Figure 5 plots minimum discernible signal level as a function of frequency together with a plot of atmospheric noise against frequency. The noise is that anticipated from a 10 to 30 metre antenna in a bandwidth equal to that of the receiver, or 3.7 kHz. The figures have been derived from information published in the ITT Reference Data for Radio Engineers and based on a noise level for Australia of around 45 dB above KTB at 1 MHz. Based on figure 5 and using the range of antenna lengths specified, the receiver has adequate sensitivity for frequencies up to 350 kHz. The receiver still operates up to 500 kHz, but owing to the shaped RF response, it has a considerable reduction in sensitivity as 500 kHz is approached.

Full automatic gain control (AGC) has not been provided in the RF and IF circuits, partly because the LF353 amplifiers did not quite lend themselves to control of gain and partly because ionospheric fading was not anticipated on this band. Had AGC been contemplated, gain controlled amplifiers such as the Motorola MC1590 or the Plessey SL6120 might have been a better choice for RF amplification. Because RF gain is manually controlled, some care must be taken in setting the RF gain control to prevent receiver overload when tuning to a very strong signal, such as the local airport beacon. The placing of the gain control at the RF amplifier input might appear open to question as attenuation at its input effectively degrades the receiver noise figure. On the other hand, it is the best place to control the input signal level to prevent cross modulation in the amplifier. Furthermore, at the frequencies concerned, incoming noise is generally predominant over receiver noise and the noise figure is not so important.

The main nuisance of no AGC was found to be the audio overload which occurred when shifting the tuning from a weak signal to a very strong signal. This effect was reduced by applying a form of AGC which lowered the gain of the last IF stage on very strong signals. To achieve this, DC voltage is rectified from the IF output of the stage and is applied to a germanium diode connected at the stage input. The variable resistance of the diode acts as the shunt element of an inverted L network. The higher the signal voltage, the higher is the diode current, the lower is the resistance of the shunt element and hence the greater is the loss in the network.

One might well ask why this AGC system was not applied at the RF input as is usually done. This, in fact, was experimented with but found to encourage cross modulation from strong stations within the passband of the RF filter. This is a problem with broadband RF stages. There is no selective tuning to attenuate the level of the strong signal and the variable slope gain characteristic, needed for AGC control, is also a good mixing medium for the strong signal to cross modulate any other signal.

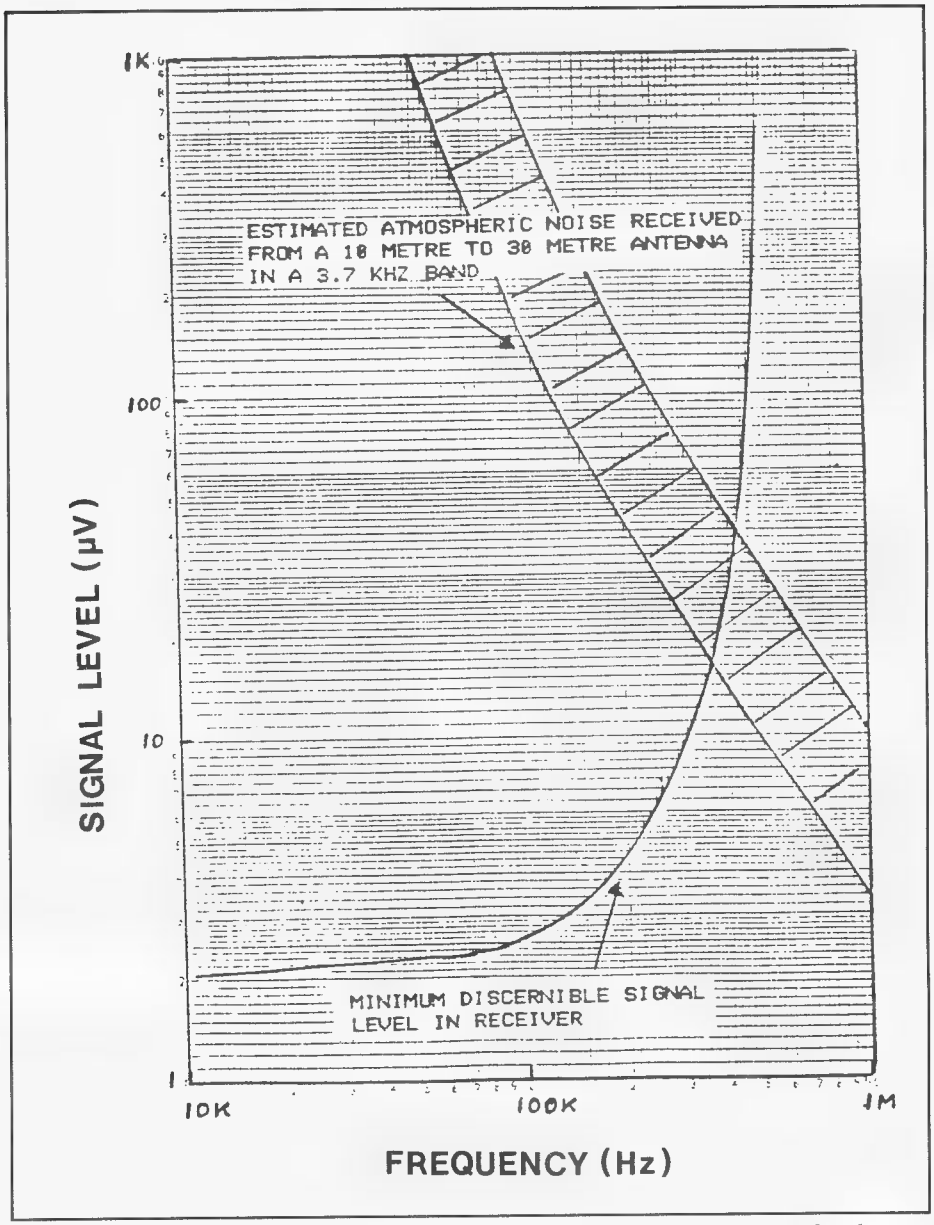

Figure 5 Minimum discernible signal level & estimated atmospheric noise level

Alignment

The only tuned circuit is the trap. This can be aligned by feeding a modulated signal at a fairly high level into the receiver input at a frequency just above 500 kHz and adjusting the series trimmer for minimum audio output. One might choose to select the frequency of the lowest frequency local broadcast station, as did the writer. In the writer's case, the receiver was tuned to 37.5 kHz and the trap set for

minimum signal from 5UV (refer to the previous discussion in the section on the RF circuit).

The only other possible adjustment is the setting of the heterodyne oscillator frequency to cover the frequency range of 465 to 955 kHz, over the tuning range of the coarse potentiometer control. This is done with the fine potentiometer control set to centre position. Trimming of the capacitance across pins 2 & 3 of N3 and the fixed resistor at pin of N3 could be necessary to suit individual samples of the XR2209 package. Its frequency range can be checked using a frequency counter connected across its output or by feeding the receiver input with a signal generator set to the extremities of the input frequency range, 10 kHz and 500 kHz.

Notes on Assembly & Components

There is nothing particularly critical about the receiver layout except that the circuit wiring should flow from input to output in order, as is normal practice and outputs should be kept away from inputs. It is not an arduous task to hardwire the whole unit (except for controls) on a small piece of Vero board. The writer's experimental receiver was fitted on a card space of 12 cm x 10 cm.

All the inductors used are the miniature ferrite cored types such as the Siemens range of RF chokes type 878 108-S. These are about the size of a small resistor, are colour coded like a resistor and can easily be mistaken for one. There are a few precautions to observe in mounting these chokes. Unlike toroidal cored inductors, the field around them is not confined and they should be mounted with extended leads, at least 1 cm off any metal on the circuit board, to prevent change of inductance and lowering of Q. If two of them are mounted close together, they should be mounted at right angles to reduce interaction between their fields.

As a general rule, capacitors with a low resistive component should be selected for filters and tuned circuits and this also applies to the filters and trap circuit in this receiver. Most people choose ceramic capacitors for use in their projects because of their small size, but their resistive component varies from sample to sample in a batch and it is often quite high. Unless they can be carefully selected for low resistive component, using an impedance bridge or Q meter, they should be avoided if possible. Mica capacitors are good but are usually much larger. There are some high quality ceramic capacitors made, such as the Vitramon VP31 range, but they might be difficult to obtain at the local electronics store.

The only other components, which require particular mention, are the capacitor and variable resistances used to control the frequency of the heterodyne oscillator. The capacitor across pins 2 & 3 of N3 should be a good stable type (perhaps a mica) and the potentiometers should be non-inductive with good resolution. Good quality one-watt carbon or cermet types of potentiometer are suggested to give nice smooth tuning. This is emphasised because there are some very poor potentiometers on the market today, particularly in the miniature variety. On of their faults is the high degree of mechanical backlash which seems to be caused by the elasticity of the bush sealing the shaft. Fortunately this backlash is steadied when the shaft is loaded down by the reduction gear on a tuning dial.

What Can Be Heard

The VLF and LF bands have their own unique useful characteristics. Transmission is by ground wave, virtually unaffected by reflection from the ionosphere and because of this, transmission is highly predictable and very useful for direction finding and other forms of radio navigation. Atmospheric attenuation falls as frequency is lowered and given sufficient radiated power, signals at VLF travel large distances around the earth's surface. A difficulty is the massive aerial system needed to achieve some order of antenna efficiency and hence radiated power.

Another limitation is the restricted amount of channel space, not suitable for wideband systems. For example, one television channel of around 6 MHz bandwidth, on its own, takes up 20 times more band space than the whole of the VLF and LF spectrums put together.

Radio waves are highly attenuated when passing through water but waves in the VLF region are attenuated the least. (This was discussed in an article by the writer in Amateur Radio, April 1987.) Because of the comparatively low attenuation, the VLF band is used for communication to submarines.

Within the Australian region, there are many strong signals transmitted in the VLF and LF band and the part of the MF band tuned by the receiver. Included in these are the following:

Omega navigation system can be heard in a frequency band of 10 to 13 kHz. There are actually five different frequencies transmitted which are switched in a certain order of eight segments in a ten second time frame. One of the Omega stations is located in Victoria, Australia.

The North West Cape VLF station can be heard with a frequency shift of 100 Hertz between 23.25 and 23.35 kHz.

A proliferation of aeronautical homing beacons (known as non-directional beacons or NDBs) within the spectrum of 200 to 420 kHz, transmit continuous carrier with morse ident code and some also with voice aerodrome traffic or information.

Australian maritime coastal radio stations operate with CW on a range of fixed frequencies between 420 and 490 kHz and listen for merchant ships on 425, 468, 480 and 512 kHz. The maritime distress frequency is 500 kHz.

Throughout the world, there are several stations in the VLF-LF spectrum which transmit standard time and frequency. GBR (Rugby UK) is well known for its time services on 16 kHz. MSF (Rugby) also transmits on 60 kHz. At low frequencies, these typical signals are ducted around the earth in a type of wave guide formed by the D layer and the earth. With a bit of luck, one might pick up some of these.

There are various teletype services which can be heard from time to time. Of course it is difficult to identify who they are unless you can decode their signals.

In Europe, frequencies between 150 and 300 kHz are used for long wave broadcasting but at these frequencies, distances are too great for reception within Australia.

For those enthusiasts who are interested in short wave listening and identifying various stations, there is another field of endeavour in long wave listening.

Other Options

We have discussed the design of a complete VLF-LF receiver but there are a few other simple options which might be attractive to others interested in these bands. If you have an existing receiver with a 455 kHz IF channel, you could build just the RF end of the receiver described and feed the XR2008 mixer output into the second receiver IF stage, via a switch which selects either the VLF-LF front end, or the existing receiver RF end.

Another option is to use the VLF-LF RF end as a converter and feed the mixer output into the second receiver tuned at the low frequency end of the broadcast band. A frequency would have to selected clear of strong broadcast carriers and the connecting lead would have to be carefully shielded. The capacitor across pins

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MORSE CODE IS A MYTH!

MERVYN EUNSON VK4SO
BOX 1513 GPO BRISBANE 4001

True, Morse never did devise the simple code that bears his name-fame (or blame) is heaped on the wrong man! Nor did he invent the electric telegraph, as commonly supposed.

Samuel Finley Breese Morse was a painter of fashionable portrait miniatures. Born in 1791 at Charlestown in Massachusetts. Known as Finley to family and friends, others addressed him as Professor (he tutored in art at the University of New York). He was without scientific learning or engineering skill.

Morse, blind to massive conflicting facts, always claimed that he alone invented the first electric telegraph in 1832, though naught was done to develop it for several years (then his efforts produced a dud!).

But as early as 1795 systems had been demonstrated using static electricity. Then after Alessandro Volta produced the first chemical battery in 1801, history's path is strewn with ingenious telegraphs applying the new electromotive force. The first commercial success, patented in England in 1837, was that of the patnership of William Cooke and Charles Wheatstone, being a direct-reading instrument with multiple line wires and five needles. Subsequently they reverted to a two-wire system and one centre-zero galvanometer needle, deflected left-right by separate keys.

This latter method was a refinement of that pioneered in 1825 by Ludovitsch Schilling of Kronstadt, a Russian nobleman, who built a line for Alexander I between the Czar's palaces at St. Petersburg. Others effected improvements, notably Karl Gauss and Wilhelm Weber at Gottingen in 1833, as did Professor Steinheil at Munich in 1837, who discovered the principle of the earth return. But these were men of science, disinterested in pecuniary exploitation.

The apparatus of Cooke and Wheatstone served well in communications for English railway systems (no post offices existed before Rowland Hill introduced penny postage in 1840). And this, with a US patent before that of Morse, found favour in America as well.

All these early telegraphs featured an obsession with direct-reading methods, or in obtaining a visual record of the message (the very word "telegraph" means "writing from afar" and was coined in France to describe the Chappe semaphore of 1793). Strangely, in that great musical age none conceived the notion of aurally receiving a series of simple sounds. But then railway operators found divided concentration difficult in following the fluctuating needly by eye and simultaneously writing the message - it proved easier to copy the audible "click-clack" by ear instead.

Morse the late-comer also proposed a registering system that was woefully cumbersome and impractical. Its basis was a dictionary of selected words marked with coded numbers. The message was set in words cast from printer's type with special projections, which were rendered into electrical impulses by passing under a circuit breaker. At the receiving end a crude pantograph (made from a picture frame) caused a stylus to register a serrated line. Counting the peaks converted the message into numerals, then decoded by reference to the numbered dictionary (the illustration shown reads "SUCCESSFUL EXPERIMENT WITH TELEGRAPH SEPTEMBER 4 1837"). None of this was original, for the inventor Edgeworth in 1794 used a numbered dictionary with his semaphore.

Grossly inadequate, the wretched failure along with Professor Morse would have passed into the abyss of oblivion. Among other shortcomings, it would not function beyond a line length of a few feet (he was ignorant of the law propounded by Georg Simon Ohm in 1827). As he lacked appropriate technical knowledge, Morse then sought scientific advice from Dr Gale, a university academic, who acquainted him with the discoveries of

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2 & 3 of the XR2209 oscillator would also have to be decreased to shift the oscillator frequencies up a little. Do not try to shift it up too far as the frequency limit of the XR2209 is specified as 1 MHz, although you might get it to operate a little higher than that.

In the receiver described, the IF channel was specifically designed with a narrow bandwidth and a steep out of band slope so that 10 kHz could be tuned. If an attached receiver option is used, tuning quite as low at 10 kHz might be restricted if the receiver bandwith happens to be too wide.

Considering some other options, a different type of RF amplifier could easily be used, perhaps with better performance at the MF end of the tuning range. It is strongly recommended that you stay with the XR2208 as a mixer, because of its balanced mixing type of performance and its low order of intermodulation products.

Summary

A receiver has been presented which tunes the VLF and LF bands and part of the MF band. The receiver makes use of a number of integrated circuit packages and circuit techniques, perhaps a little unusual in radio receivers. Use of the XR2209 oscillator package with resistance tuning and a broadband RF front end eliminates the need for a ganged tuning capacitor. The XR2208 operational multiplier performs as a mixer at the frequencies concerned with outstanding performance. The dual operational amplifier package LF353 has been put to work as an RF and IF amplifier. A section of an inexpensive ceramic filter is used as crystal control for a stable BFO. There are no coils to wind as all the inductors are inexpensive RF chokes of preferred value, available off the electronics store shelf.

The receiver has more than adequate sensitivity on the VLF and LF bands. Its sensitivity falls on the MF band as 500 kHz is approached.

Included in the discussion is an introduction to what can be heard on the VLF, LF and lower MF bands. Apart form the complete receiver in itself, a few alternative options have been presented on how a VLF-LF front end could be added to an existing receiver. For the keen experimenting listener, the VLF-LF bands might well be another new field of endeavour to explore. **ar**

BANDWIDTH CONTROL FOR THE VLF-LF RECEIVER

LLOYD BUTLER VK5BR
18 OTTAWA AVE PANORAMA 5041

In the VLF-LF receiver described in my previous article, AR Dec 89, the bandwidth was set at 3.7 kHz by two Murata 455 kHz Type SFD455D ceramic filters. This bandwidth is ideal for medium bandwidth type modes, such as AM speech, but wider than necessary for narrow band mode signals which exist at frequencies below 100 kHz. These signals are received in the presence of very high noise levels which are inherent to the LF spectrum and the low end of the VLF spectrum. For these signals, an improvement in signal to noise ratio can be achieved by reducing the bandwidth of the receiver. As it turns out, the bandwidth can be narrowed quite simply by switching in a minor circuit change around one of the two ceramic filters.

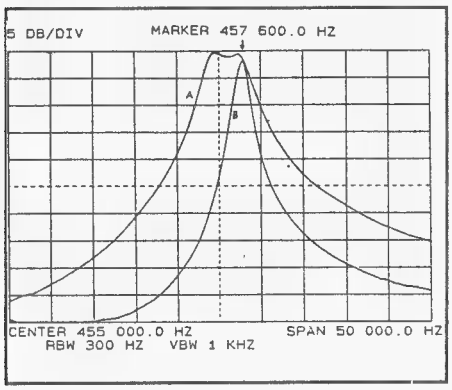

Figure 1
A. Response of the original wideband filter circuit.
B. Response of the narrow band filter circuit.

Curve A of figure 1 plots the spectral response of the original ceramic filter circuit shown in figure 2. The bandwidth of the circuit can be narrowed to less than 1 kHz, by decreasing the 56 pF inter-filter coupling capacitor to 4.7 pF and terminating the filter in a high impedance. The resultant spectral response is shown by curve B of figure 1. The high impedance can be achieved by increasing the value of terminating resistor. However, in the receiver circuit, this resistor is also an input return for the following operational amplifier. Increasing its value without a corresponding change at the amplifier inverting input would affect the DC offset of the amplifier. To avoid changing the inverting input components, the high impedance was achieved by inserting a 4.7 mH choke in series with the original 3 kOhm terminating resistor. The modified circuit for narrow bandwidth is shown in figure 3.

Examining again the narrow bandwidth curve B of figure 1, it can be seen that it peaks at 457.6 kHz. This works out quite well for centring a frequency to give an audio beat with the beat frequency oscillator (BFO) which is locked at 456.85 kHz. Referring back to the original VLF-LF article, the BFO was locked by an element in the same type of ceramic filter unit as used to control the IF bandwidth.

To achieve switching between wide and narrow band, it was found that this could easily be achieved by switching the inter-filter coupling capacitor between 56 pF and 4.7 pF and leaving the 4.7 mH choke in place for both conditions. Figure 4 shows the effect of the choke when leaving it in circuit for the wideband condition. Curve A is the spectral response of the original circuit of figure 2 and curve B is the response with the choke in circuit. It can be seen that the latter condition gives an actual 6 dB gain at the expense of around 3 dB of asymmetrical ripple in the response curve. Whilst the ripple looks untidy on paper, its effect on the practical performance on the receiver is unnoticeable. Furthermore, the 6 dB of gain improvement is also a 6 dB improvement in overall receiver sensitivity which assists reception at the 500 kHz end of the tuning range where the sensitivity falls away.

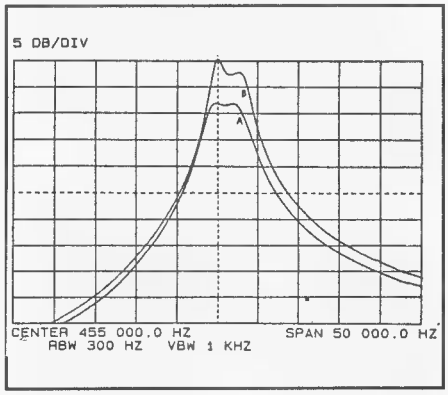

Figure 4
A. Response of original wideband filter
B. Response of wideband filter with 4.7 mH choke left in circuit

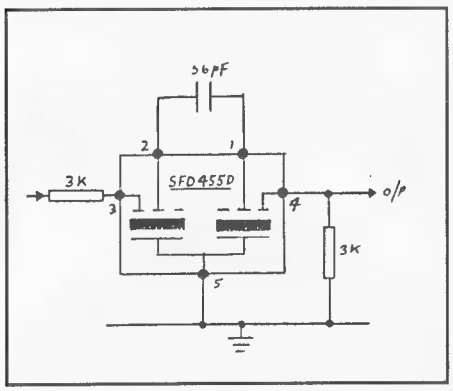

Figure 2 Original wideband filter circuit

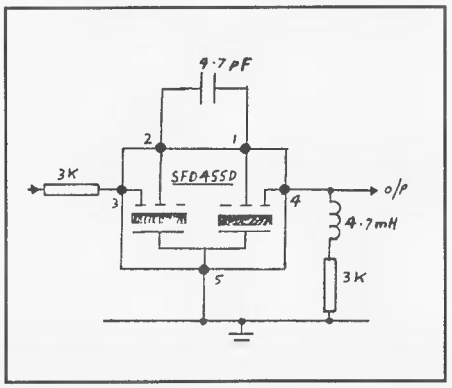

Figure 3 Narrow bandwidth filter circuit

The switchable bandwidth control circuit is shown in figure 5. This was applied to the first ceramic filter in the IF chain because it was the easiest one to access on the already wired up board. (The modification could actually be performed without even removing the card from the receiver box.) Of course, there is no reason why the modification could not have been carried out on the second filter had it been more convenient to achieve. The bandwidth switch was mounted on the receiver front panel and connected into

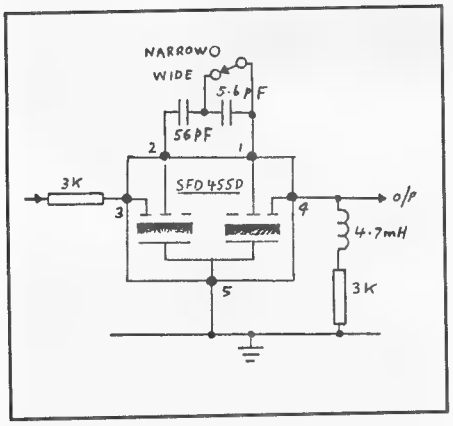

Figure 5 Filter circuit with wide/narrow bandwidth switching

the circuit board via a twisted wire pair. In the circuit shown, the 4.7 pF coupling capacitance for narrow band operation is formed from the series connection of 5.6 pF and 56 pF. Part of the 5.6 pF capacitance is made up of capacitance in the twisted wire pair to the switch. For wide band operation, the 5.6 pF section is shorted out so that the coupling capacitance becomes 56 pF.

Other Applications

The bandwidth control circuit was intended specifically for the LF-VLF receiver but it could well be fitted to any receiver with a 455 kHz IF channel to improve the reception of narrow band mode signals. The Murata ceramic filter is a very versatile little unit considering its cost and size. It can be purchased for but a few dollars and has dimensions of only 7mm x 6mm x 7mm. I have found that by altering the values of source resistance, load resistance and inter-filter coupling capacitance, bandwidth can be set at a range of values between 1 kHz and 7 kHz. (Circuit detail for a bandwidth as wide as 7 kHz was included in the previous article on the VLF-LF receiver.) Not to be overlooked is the additional application of the filter for crystal control of the beat frequency oscillator (refer again the previous VLF-LF receiver article). **ar**

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A FRONT END TUNER FOR THE VLF-LF RECEIVER

LLOYD BUTLER VK5BR
18 OTTAWA AVE PANORAMA 5041

In the December 1989 and January 1990 issues of Amateur Radio, we described a VLF-LF receiver which utilised a broadband front end. A problem with this type of front end is that it is prone to cross modulation from very strong signals or noise, outside the tuning bandwidth, but within the broadband range of the front end. When this occurs, it is necessary to reduce the RF input level sufficiently to prevent the problem. However, this also reduces the wanted signal level, possibly well into the noise floor of the receiver. To overcome the problem, we can add a front end tuner such as the one described.

A further advantage of front end tuning is that selectivity at VLF can be greatly enhanced. For example, if a Q factor of 200 can be achieved in the front end tuned circuit, the bandwidth at 10 kHz is only 10,000/200 = 50 Hz. One of the biggest problems in receiving signals at VLF is the high level of noise, both man-made and atmospheric. The VLF signals, of necessity, are transmitted in narrow band modes and restriction of bandwidth received is the most effective way of reducing the noise. Furthermore, the narrow bandwidth is also needed to separate some of the signals closely spaced in frequency. All in all, front end tuning improves the performance of the receiver immensely.

Following the publishing of the original VLF-LF receiver article, there has been feedback from a number of readers interested in the VLF-LF bands. One of these is Norm Burton, of NSW, who has been experimenting with VLF reception for at least 25 years. Norm has written in considerable detail concerning his own experiences and I have given due regard to what type of gear he has found works best at VLF. I will make reference to some of the points he has made in the text.

The Tuning System

According to Norm, at VLF it is very important to tune the aerial and there is certainly nothing wrong in doing just that. However, I have aimed at a tuned circuit system which is not resonated with the aerial. The reasons for this are as follows:

1. Various wire aerials at the home installation, at low frequencies, appear against ground much like a large capacitor in the vicinity of say 400 pF. If made part of the tuning system, this residual capacity would have made it difficult to cover the tuning range of 10 kHz to 500 kHz in four bands, as has been done using an ordinary receiver tuning gang.
2. An aim in designing the tuner was to make a high Q circuit using a high Q inductor and it was though that loss resistance in the earth system might restrict the maximum Q.
3. It was also an aim to make the tuning independent of aerial reactance constants so that any aerial could be used.

Generally speaking, I have found that, at low frequencies, the long untuned length of wire gives highest output voltage when loaded into a fairly high resistance. A value of 1000 Ohms works quite well and the original receiver was designed to load the aerial with 1000 Ohms. My initial design approach for the tuner was to couple the aerial via a voltage follower stage, which presented a high resistance load to the aerial, but drove the tuned circuit in a series mode from its low output resistance so as to maintain high Q in the tuned circuit. This was unsatisfactory as the follower stage introduced cross modulation, the very thing which the circuit was supposed to reduce.

The follower stage was ultimately substituted by a low value resistor, which shunts the aerial, but maintains the high Q. This results in voltage loss from the aerial but this loss is more than made up by voltage magnification in the tuned circuit. (The voltage gain of a tuned circuit is, of course, equal to the value of Q.)

One characteristic of the high Q circuit is that, in the presence of atmospheric static or other transient natured noise, the circuit tends to ring or oscillate on being shocked by the transient impulse. For a given Q, the decay time of oscillation is inversely proportional to frequency and at very low frequencies this oscillation is detected as an audio ring when using the BFO. Because of this effect, a Q control switch is provided which controls the value of resistance in series with the tuned circuit and hence its Q. The idea is to set the switch for the narrowest bandwidth possible consistent with a tolerable amount of ringing in the presence of noise.

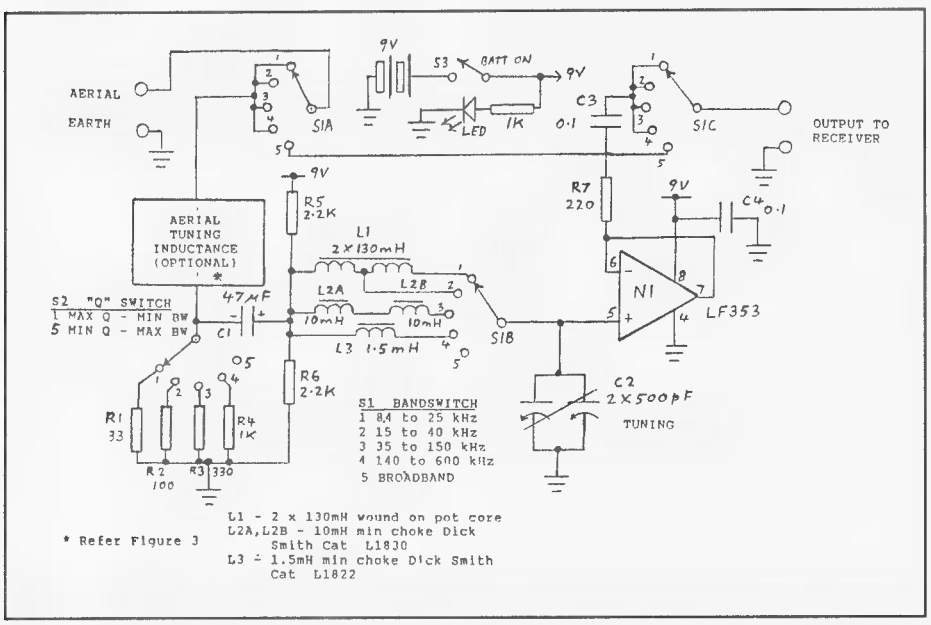


Figure 1 VLF-LF Front end tuner

Whilst the circuit design has been based on an untuned aerial, it does not inhibit additional tuning of the aerial circuit to further improve performance. The option of doing this is dealt with in the section headed "aerials".

The Circuit

The circuit of the front end tuner is shown in figure 1. The circuit provides a tunable frequency range of 8 kHz to 600 kHz in four bands switched by SW1B. Other sections of the band switch, SW1A & SW1C provide direct coupling of the aerial to the receiver for broadband operation when the switch is set to the fifth position.

The tuning system is formed by inductors L1, L2, or L3, which are resonated with variable capacitor C4. This is a two section receiver tuning gang with a maximum capacity approaching 500 pF per section. Inductor L1 is a pot core assembly with two windings, each 130 mH. The windings are connected in series for band 1 to tune between 8 kHz and 25 kHz. One single winding is used for band 2 which tunes between 15 kHz and 40 kHz. Two 10 mH miniature chokes connected in series are used for band 3 which tunes between 35 kHz and 150 kHz. A single 1.5 mH miniature choke is used for band 4 which tunes 140 kHz to 600 kHz.

The ready wound pot core inductor is one donated by Norm Burton. The 10 mH and 1.5 mH chokes are a miniature type supplied by Dick Smith Electronics.

Resistors R1 to R4, switched by SW2, terminate the aerial and determine the loss resistance added to the tuned circuit and hence the circuit Q.

The high input impedance of voltage follower stage N1 provides coupling to the receiver input with minimal loading of the tuned circuit. This is necessary to maintain the high value of Q in the tuned circuit. For the voltage follower, one half of a JFET operational amplifier package type LF353 is used. This has good high frequency performance and was also used in the VLF-LF receiver for RF and IF amplification. (The other half of N1 package is not used. It was originally intended as an interface for the aerial but, as explained earlier, its use proved to be unsatisfactory.) As an alternative to the amplifier package, an emitter follower stage could be used. For this application, a Darlington connected transistor pair might be advisable to achieve sufficiently high input resistance.

For anyone interested in duplicating the circuit, two components specified in the circuit might not be readily available at the local electronics store. The first is the tuning gang, an item not in good supply these days. The best bet is to recover one from a discarded broadcast receiver. Some gangs only have about 350 pF maximum capacity per section but a 3 section gang in one of these would do the job.

The second item is the pot cored inductor. This is an ideal type of inductor for the low frequency bands, if one can obtain the pot core parts assembly to wind one, or otherwise obtain one ready wound with a suitable inductance. An alternative idea was tried out with eleven of the Dick Smith 10 mH chokes connected in series to make up 110 mH. This tuned band 2 from 15.7 to 67 kHz. To lower the frequency for band 1, an 820 pF fixed capacitor was switched across the tuning gang with a fourth switch bank of SW1. This gave a tuning range for band 1 of 11.3 to 15.9 kHz. The maximum circuit Q achievable with the 10 mH chokes was around 50 to 100, not as good as the pot cored inductor, but still quite good.

Changes To Receiver

The front end tuner has been built as a stand alone unit which is simply inserted in the aerial feeder cable to the receiver. However, because of its addition, the 530 kHz trap in the receiver is no longer required and disconnection of the trap provides some improvement to the low receiver sensitivity at frequencies approaching 500 kHz.

Another change is the addition of a selective audio filter. According to Norm Burton, a good audio filter is essential for receiving VLF signals and he suggests a filter bandwidth of 100 Hz or less. Encouraged by this, a simple resonant filter was added to the audio stages of the receiver as shown in figure 2. The tuned circuit is formed by another of Norm's pot core inductors (130 mH) which is resonated with a 0.12 µF capacitor. The circuit is driven in a series mode (much like the front end tuner) from the low output resistance of amplifier N5B. As there is voltage gain (equal to Q) in the tuned circuit, the resistive output divider is used to prevent a steep rise in signal level when the filter is switched in.

The frequency of the filter is 1200 Hz, worked out as follows: In the narrow IF mode, the centre frequency is 457.6 kHz. The beat frequency oscillator is needed to receive the narrow band modes and this runs at 456.4 kHz, 1200 Hz lower than the intermediate centre frequency. Hence, maximum signal beat occurs at a fre-

Table 1

Band	Bandwidth "Q" Position 1 Frequency (kHz)	Bandwidth (Hz)	Q
1	10	48	208
1	15	60	250
1	20	84	238
1	25	132	189
2	16	85	188
2	25	121	207
2	35	234	150
3	40	610	66
3	70	802	87
3	120	1140	105
3	150	1360	110
4	150	1830	82
4	200	3480	57
4	300	2910	103
4	400	2300	174

Table 2

Bandwidth For Different "Q" Switch Positions
At 15 kHz On Band 1

Switch Pos	Bandwidth (Hz)	Q
1	60	250
2	83	181
3	145	103
4	226	66
5	360	42

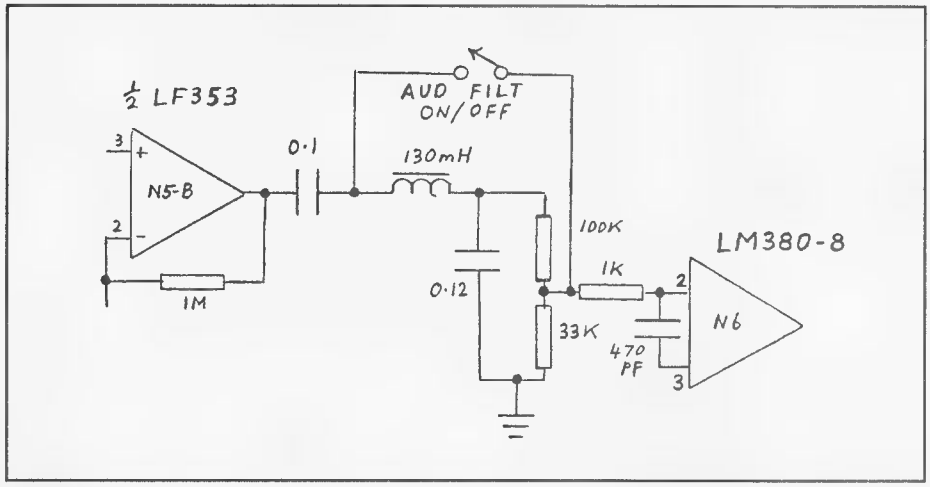


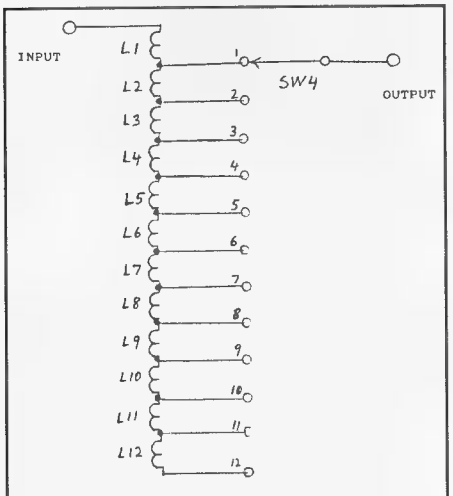
Figure 2: Addition of 1200 Hz Audio Filter to the Receiver

quency of 1200 Hz and this is the tuned frequency of the filter. The bandwidth of the filter is 100 Hz and it is very effective in reducing much of the low frequency hash which gets through in spite of the narrow RF bandwidth.

Operation

Operation of the front end tuner, in conjunction with the receiver, can be a little tricky as the front end is not ganged to the receiver tuning. One method of tuning is to set the band switch to the broadband position and first locate the station with the receiver tuning dial. The band switch is then set to the appropriate band and the tuning gang is set for maximum signal level. Care must be taken not to tune in to the frequency of a strong signal which would simply enhance cross modulation by that signal. Tuning on the lowest frequency bands is very sharp and on the unit constructed, a 2.5 to 1 reduction gear was fitted to the tuning knob to assist in adjustment. A calibrated scale marked in frequency for each band was also added to simplify setting of the front end tuning near the frequency marked on the receiver tuning dial. With this aid, the front end tuning is then simply trimmed for peak signal level with little chance of false tuning.

A problem at VLF & LF is noise from mains operated equipment in the local vicinity and particularly in one's own house. I find it necessary to turn off fluorescent lamps, triac controlled light dimmer switches and TV sets. The TV line time base at 15625 Hz, in the middle of the VLF band, is a particular nuisance. This type of noise tends to disappear after midnight when everyone has switched things off and gone to bed.



L1 – 150µH min choke
L2 – 1mH min choke
L3-L12 – 10mH min choke

Figure 3: Aerial tuning circuit

Measured Performance

Table 1 lists measurements taken of bandwidth and Q for various frequencies in each band of the tuner and with Q set maximum. It is interesting to observe the high Q factors obtained, particularly for bands 1 & 2 which use the pot core. This is something which could not be achieved in the early days, before ferrite cores, unless regeneration was applied.

Table 2 lists measurements taken of bandwidth and Q at 15 kHz on band 1 for different settings of the Q switch. This shows that a 6 to 1 range of bandwidth and Q can be selected.

Aerials

At low frequencies the usual wire aerial is but a fraction of a wavelength long and as a general rule, the more wire put up in the air, the greater is the signal level we will capture. As one would expect, at the home location the longest of three wire aerials available gives the highest signal level. The signal level is also improved by about 6 dB when all three wires are paralleled together.

Earlier mention was made of tuning the aerial and this is an optional addition which can be made to the front end circuitry. By resonating the inherent capacitance of the aerial with series inductance and loading the output into the terminal resistance set by the Q switch, a further gain in signal level of at least 10 dB is achieved. The three paralleled wires at the home location measure a capacitance of around 1000 pF and resonance with this, over most of the VLF band, was made possible by tapping along the bank of series connected 10 mH chokes used in a test previously discussed. Resonance was found to be fairly broad and the 10 mH increments were proved to be small enough to allow peaking of the signal.

The front end unit was ultimately fitted with a further switch, connected to ten of the 10 mH chokes and two other chokes, for tuning the aerial. The circuit diagram of this is shown in figure 3 and shown as an optional block in figure 1. The 10 mH chokes provide aerial tuning adjustment in fine steps between 13 kHz and 50 kHz. As there were only two spare positions on the 12 position rotary switch for the higher frequencies, one had to be satisfied with 1.15 mH to resonate around 150 kHz and 150 µH to resonate around 400 kHz. As stated before, tuning is quite broad and even with this compromise, some gain is achieved over the whole of the higher frequency range by the addition of the inductors.

As is well known, the radiation resistance of an electrically very short aerial is but a fraction of an Ohm and at resonance we see a low resistance, essentially that of the earth, in series with the loss resistance of the inductor. As it turns out, this works out quite well to match into the low terminal resistance set by the Q switch. It must be pointed out, if not obvious, that the inductance values used in figure 3 are selected for a particular aerial capacitance and might have to be varied to suit another particular aerial.

At this stage, a brief mention of Norm Burton's aerial system might also be of interest. He uses a 33 ft 6 wire cage with 42 ft of 4 wire cage down lead. The cage at the top increases the capacitance to ground and raises its effective length and hence its radiation resistance and aerial efficiency. He also uses a frame aerial which gives lower signal level but enables him to phase out some of the interference he gets from localised power lines. Norm tunes all his aerials and considers it essential for good reception at these low frequencies.

Some Final Remarks

It seems very clear that a highly selective front end is essential for good reception at VLF. A narrow bandwidth is needed to restrict the noise and this is more easily controlled in the IF stages of a superheterodyne although some form of front end tuning is clearly desirable to prevent cross modulation from strong local stations. What might seem less apparent is the fact that the noise level on this band is so high that the noise itself can cross modulate the desired signal. It seems essential to restrict the noise bandwidth as much as possible before amplification takes place and herein lies the need for the highly selective front end.

All this ties in with much of what Norm Burton has told me. He has two superheterodyne receivers and a Marconi CR200 TRF receiver which tune the VLF band. The CR200, which has two tuned RF stages before detection, outperforms the other receivers both in minimising noise and separating one station from another, not to mention the odd spurious responses the superhets happen to generate. He has also pointed out how single valve regenerative receivers were successfully used on these low frequency bands in the early years. By using regeneration, effective Q would have to be high with resultant narrow bandwidth and good selectivity. I am almost tempted to build one up to see how well it works.

Dick Hope VK4DLJ informs me that there is quite a lot of interest in ELF-VLF-LF in the USA and there is an organisation called the Longwave Club of

continued on page 25

A Front End Tuner from the VLF-LF Receiver

Continued from page 11

America. This club also distributes a magazine called "Lowdown". Perhaps, in Australia, we should be pressing for an amateur radio section of the bands at these low frequencies. Judging by the lack of signals around 40 to 100 kHz, this spectrum does not appear to be greatly utilised.

To finalise the discussion, we have described a front end tuner which improves the performance of the VLF-LF receiver immensely. In fact, it would be a useful addition to place in front of any receiver which happens to tune these bands. With separate sharp RF tuning, Q switch and possibly aerial tuning, the receiver is a little complicated to adjust, but once mastered, the results are certainly worth while. One further control to be watched is the receiver RF gain. With all the extra gain in the front end tuned circuits, it is very easy to lock up the receiver with too much signal level.

One might ask why the tuning could not be simplified by ganging the front end tuned circuits with the receiver oscillator tuning. To make a highly selective tuned circuit at 10 to 30 kHz accurately track, at 455 kHz difference, with the oscillator circuit at around 465 to 485 kHz, seems a highly difficult, if not impossible task. It seems that with the superheterodyne we must either trim the front end manually or tolerate the inferior performance of broader tuning. **ar**

VLF-LF AND THE LOOP AERIAL

LLOYD BUTLER VK5BR
18 OTTAWA AVE PANORAMA 5041

In the December 1989 issue of "Amateur Radio" we introduced a design for a receiver which tuned the VLF-LF bands, and followed up with further articles on bandwidth control and front end tuning. We now introduce loop aerials as another adjunct to the VLF-LF receiving equipment.

We begin with some theory on loop aerials and how they reduce the level of local noise. Some experiments, carried out by the writer, are described together with a circuit for a loop tuner and preamplifier. The discussion extends to the problems of amplifier noise and the advantages of tuning the loop.

Loop Aerial Theory

As discussed in our previous articles, a major problem in receiving VLF and LF signals is the high level of local noise generated from noisy power lines and consumer electrical equipment. In the presence of this type of noise, the received signal to noise ratio can be improved with the use of a loop aerial.

To explain this, we must briefly discuss the fields around a radiating element. At distances up to around half a wavelength, the induction or near field is prominent but it falls away at a greater rate with distance than the radiation field. At distances greater than one half wavelength, the radiation field is prominent. The relationship between field strength and distance is as follows:

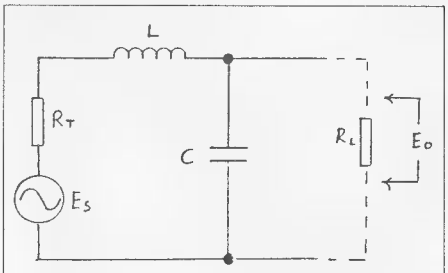
1. The electric component of the induction field decreases with the cube of the distance and dB = 60 log (d2/d1) where d2 and d1 are the relative distances.
2. The magnetic component of the induction field decreases with the square of the distance and dB = 40 log (d2/d1).
3. Both the electric and magnetic components of the radiation field decrease directly with distance and dB = 20 log (d2/d1).

The effect of all this is that in the near field, the electric component is much stronger than the magnetic component. This is illustrated graphically in figure 1.

At VLF and LF (10 to 300 kHz), we are concerned with half wavelengths between 500 and 15,000 metres and reception of localised noise is clearly in the induction or near field region. The shielded loop aerial is sensitive only to the magnetic component and since this is lower in level than the electric component in the near field, the level of noise interference is reduced. Furthermore, if the source of interference is from a different direction to that of the signal to be received, the noise is further reduced by the directional properties of the loop. The loop has a very sharp null at right angles to the plane of the loop and it can be rotated to position the noise source at the null.

The equivalent circuit of the loop aerial coupled to a load resistance R1 is shown in figure 2. Es is the voltage induced into the loop, Rt is the resistance of the circuit (the sum of radiation resistance and loss resistance), L is the inductance of the loop, C is the shunt capacitance of the loop with its cable coupled to the load and Eo is the output voltage across the load.

When the loop plane is in line with the



Es = Induced Voltage
Rt = Loop Resistance (sum of Radiation Resistance & Loss Resistance)
L = Loop Series Inductance
C = Shunt Capacitance
R1 = Load Resistance
Eo = Output Voltage

Figure 2. Equivalent circuit of the loop aerial.

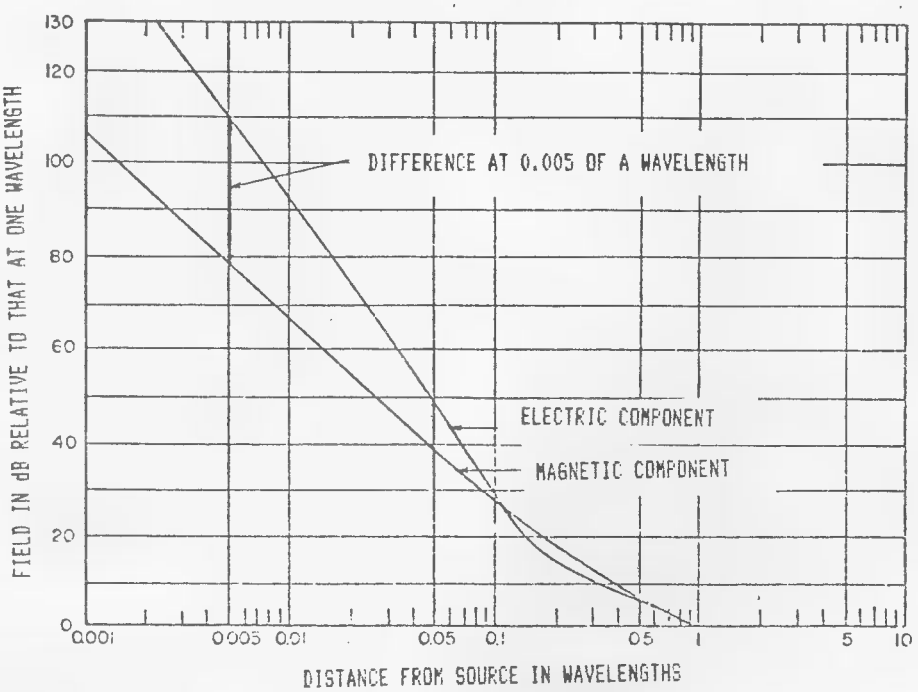


Figure 1. Comparison of electric and magnetic components of received field up to distances of one wavelength from the source.

direction of signal for maximum signal level, induced voltage Es is given by the following formula (valid providing the loop dimensions are small compared to a wavelength):

Es = $(2\pi eNA)$

where Es is expressed in μV

e = Field strength in μV/metre

N = Number of turns

A = Area of loop in square metres

λ = Wavelength of the signal in metres

We can also express the formula in terms of frequency (f) as follows:

Es = $(2\pi eNAf)/V$

where V = Wave velocity (3x10 metres/sec)

From the formula it is clear that the induced voltage is directly proportional to both the loop area and the number of turns and the larger we make either of these, the higher is the induced voltage. However, increasing these also increases the series inductance and shunt capacitance and depending on frequency, their reactances have a profound effect on the actual voltage Eo delivered to the load.

Resistance Rt is also in series with the load but its value is normally low enough to make little difference to the voltage delivered to the load.

Resonance

The loop aerial has a natural resonant frequency at which the reactance of L equals the reactance of C and at which the response peaks such that the output voltage Eo equals the induced voltage Es multiplied by the Q factor of the circuit. Clearly there is much to gain by operating the loop in a parallel tuned mode and this can be achieved at any frequency lower than the natural resonant frequency by simply adding shunt capacity across C. At frequencies above the natural resonant frequency, resonance is not possible and good performance is better achieved by decreasing the number of turns on the loop to make natural resonance equal to or above that of the frequency used.

To achieve good performance in a resonance mode at a wide range of frequencies, a number of loop aerials with different numbers of turns, or one with a selectable number of turns, is needed. At low frequencies, a large number of turns is desirable to achieve good signal sensitivity but at higher frequencies a lesser number of turns might have to be used to raise the natural resonant frequency. Referring back to formula (2 we see that induced voltage Es is proportional to both frequency and number of turns so that whilst we lose signal level with less turns, this tends to be compensated by the increase in frequency.

As the output voltage Eo is proportional to the Q factor at resonance, it is important to make the load resistance R1 a high value to prevent the lowering of Q. This calls for coupling directly into an amplifier with a high impedance input.

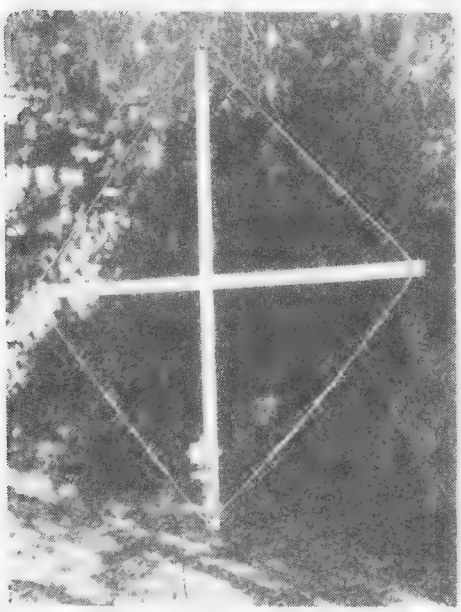


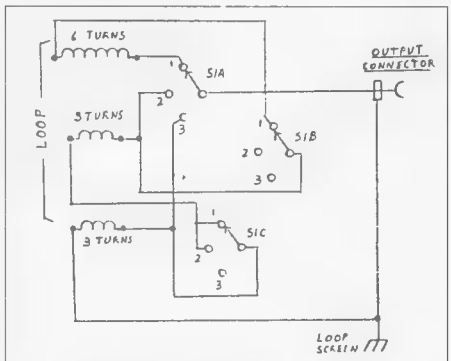
Figure 4: Loop Aerial assembly using 12 core computer cable

Shielded Loop

A multi-turn shielded loop can be constructed in many ways. The multi-turns can be spaced laterally, or in line, or bunched. They all seem to work but the essential requirement is that the shield, whilst fully enclosing the wires, must be discontinuous at one point (usually the loop apex) so that the shield does not form a shorted turn and upset the magnetic properties of the loop.

The writer found a simple way to make a shielded loop using 12 core computer bus cable. This is wrapped in conductive foil and has a heavy drain wire in contact with the foil. The loop of cable, 800mm square, is cleated to two crossed sections of light timber. The ends of the cable terminate at the base of the loop where individual wires are series joined and the drain wire and foil ends are paralleled to what becomes the cold end of the loop winding. At the apex of the cable loop, the drain wire and foil are cut so that the shield is discontinuous.

Measurements on the loop showed that 12 turns gave a natural resonant frequency of 210 kHz, 6 turns a frequency of 450 kHz and 3 turns a frequency of 730 kHz. Inductance measured around 500, 120 and 35 microhenries respectively for the different numbers of turns. As it was required to operate the loop aerial up to 500 kHz, a switch was fitted at the base of the loop to select either 12, 6 or 3 turns. The circuit arrangement is shown in figure 3. It should be observed that both ends of the unused turns are disconnected when 6 or 3 turns are in use. This is very important because if one end of the unused turns is left connected, the unused turns add extra capacity and lower the resonant frequency.



S1 3 Pole 3 Pos Rotary Switch

1 12 Turn Loop

2 6 Turn Loop

3 3 Turn Loop

Figure 3. Loop switching circuit.

The loop aerial using computer cable is shown in figure 4. It was assembled as an experimental unit and not intended, in its present form, to be weatherproof.

To resonate the loop, a 12 position switch connects a range of parallel capacitance values up to 0.47 microfarad which enables tuning down to 10 kHz with the 12 turn loop. The switched capacitor circuit is included in figure 5. With this arrangement, Q factors above 50 kHz were within the range of 13 to 20. At lower frequencies, the Q is lower and was measured as 6 at 18 kHz.

The dynamic impedance of the tuned circuit can be as high as 10,000 ohms at certain frequencies and hence the circuit is interfaced with the high impedance input of an operational amplifier. The amplifier is set for a maximum gain of 10 to increase further the signal level from the loop which, even with tuning, produces a much lower signal than that received from a random wire of reasonable length. The amplifier is provided with a switch to reduce its gain to unity in the event of very high signal levels causing cross modulation. This precaution has so far proved unnecessary.

The tuning capacitors and pre-amplifier have been fitted in a separate box so that it can be located at the receiver end of the coax cable which feeds the loop aerial. With this arrangement, the cable capacitance also forms part of the parallel tuning capacitance. At these low fre-

quencies, the only effect of this capacitance is to limit the maximum resonant frequency of the loop for a given number of loop turns. Coax cable (such as RG58) has a typical capacitance of around 100 pico-farad per metre. The loop capacitance is around one nano-farad so that a few metres of cable does not make a significant difference. The system can still be satisfactorily tuned with 6 metres of coax cable.

The loop tuning system was used in conjunction with the VLF-LF front-end tuning system and the VLF-LF receiver described in previous issues of "Amateur Radio". The complete equipment is shown in the photograph, figure 6. The loop tuner is on top of the front end unit at the left. The receiver is at the right.

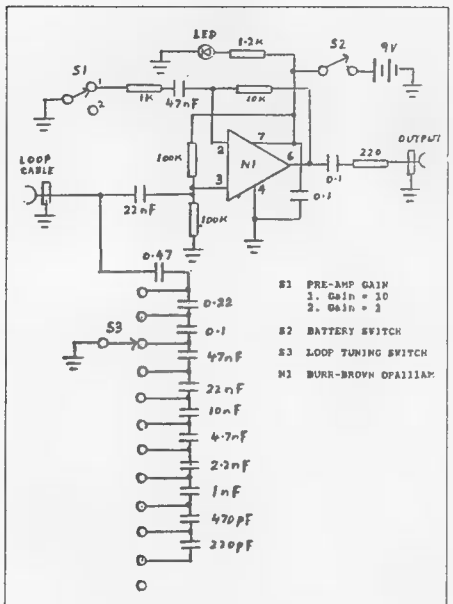
In the loop aerial discussed, switching of the number of loop turns is provided by a 3x3 rotary switch. This must be fitted at the base of the loop and could be inconvenient if the loop aerial were located outside and inaccessible. A relay circuit could be devised which would replace the switch and be controlled remotely at the receiver.

Amplifier Noise

When operating VLF-LF using a wire aerial, the atmospheric noise level received is normally well above the noise floor of the first amplifier and amplifier noise is insignificant. With the loop aerial, the signal pick-up is much lower and when the atmospheric noise level is low, the minimum discernible signal level can be set by the amplifier noise floor rather than the atmospheric noise level. It is therefore important to select a pre-amplifier with a low inherent noise, much as one would do for a VHF or UHF front end.

For the amplifier used in the circuit of figure 5, a Burr-Brown low noise FET operational amplifier type OPA111AM was selected. This is specified as having the low voltage noise figure of 6 nanovolts per root hertz of bandwidth with the negligible current noise characteristic of the FET input circuit. It has a gain-bandwidth product of 2 MHz and hence it can maintain the gain of 10 up to a frequency of 200 kHz with a falling response at higher frequencies down to a gain of 4 at 500 kHz.

Another choice for a low noise amplifier could have been the bi-polar input Precision Monolithics type OP27 amplifier. This has a voltage noise of only 3 nano-volts per root hertz of bandwidth but, having a bi-polar input, there is a current noise component which would add noise when connected across the high impedance tuned loop circuit (reference 2). The amplifier has a gain-bandwidth



S1 PRE-AMP gain
1. Gain = 10
2. Gain = 1
S2 Battery Switch
S3 Loop Tuning Switch
N1 Burr-Brown OPA111AM

Figure 5: Loop aerial tuning & Pre-amp circuit

product of 8 MHz and hence could maintain the gain of 10 well up to 800 kHz.

A further approach might have been to use one of the low noise MOSFET VHF transistors such as the BF981.

Of course, good signal to noise ratio also gets back to the design of the loop for highest possible signal voltage. Recapitulating previous parts of our discussion, signal voltage is increased with more turns or larger area (consistent with natural resonance being not less than the operating frequency) or by designing the form of the loop for the highest possible Q factor.

Loop aerial circuits are frequently published with amplified signal fed back to the loop to form what they call a Q multiplier. This, of course, is a different name for what has been known as regeneration or reaction. Feedback in phase with the input signal raises the effective Q of the circuit to increase its gain and reduce its bandwidth. For the writer's receiving system, feedback in the loop system was not considered necessary as the loop amplifier was coupled into the VLF-LF front end, previously described in "Amateur Radio". This front end, with Q factors up to 200, has itself adequate gain and selectivity.

There is also a disadvantage with using regeneration in that the noise generated by the amplifier is also fed back to be re-amplified. Whilst the regeneration narrows the loop bandwidth and reduces the bandwidth of the incoming noise, it actually increases the level of the amplifier noise within the band.

Some Other Loop Forms

The natural resonant frequency of the loop and hence its upper frequency limit for a given number of turns, can be increased by spacing the wires and spacing the shield from the wires so that residual capacity is reduced. As it turns out, the loop aerial also gives quite good noise rejection without any shield at all. With this arrangement, the residual capacity can be reduced to provide a considerable increase in the upper frequency of the loop.

Another loop aerial assembled by the writer consisted of 20 turns of unshielded wire spaced in line with a separation of 10mm between turns and forming a 0.8 metre square. To achieve the spacing, the wire was wound around four pieces of dowelling fitted through two wood cross pieces. This aerial measured an inductance of about 500 microhenries and had

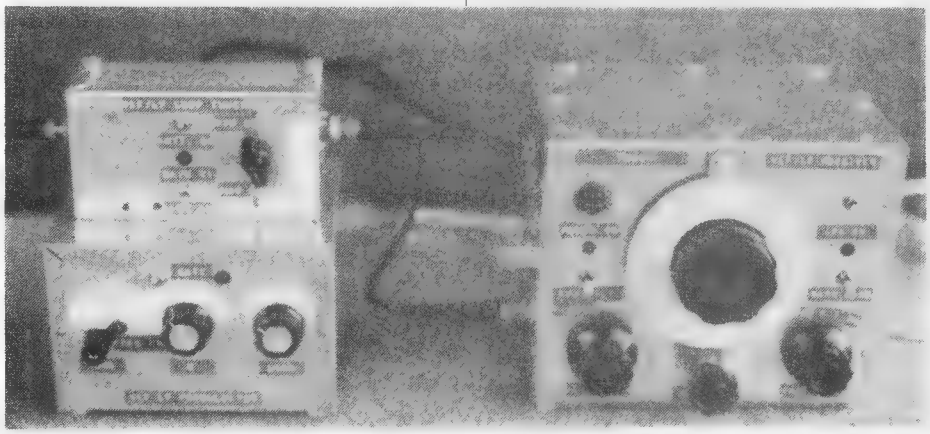


Figure 6: The receiving equipment. The loop tuner is upper left, the receiver front end tuner is lower left and the receiver is on the right.

a natural frequency of several hundred kHz. (The actual frequency was unfortunately not recorded.)

The wire on the 20 turn loop was eventually replaced with shielded wire. Its second form is shown in figure 7. At the apex of the aerial, the shields on each of the 20 wires were cut and all joined together on either side of the cut. The shields were also joined at the base of the aerial and connected to the earth side of the feeder cable. The inductance of this aerial measured much the same as that of the previous aerial with unshielded wire but natural resonance was lowered to 100 kHz. All in all, the performance in receiving signals at VLF appeared much the same as for the unshielded loop. This raises a question whether the shield is much value at these low frequencies where the loop dimensions are very small compared to a wavelength. At these frequencies, there might be merit in using the unshielded loop to take advantage of the higher upper frequency limit achieved.

In a further form of loop aerial, a single turn of large area can be used. Clarrie Castle VK5KL described a single turn loop aerial for 1.8 MHz in March 1982 issue of "Amateur Radio". The aerial was formed by a single loop of around 9 metres of coaxial cable with its outer braid conductor cut at the loop apex. The outer braid thus formed the shield around the inner looped conductor. With lower frequencies in mind, the writer st up such a loop using 9 metres of RG58 and carried out some tests. The resonance measured 2.5 MHz. At 1.8 MHz, the loop resonated with around 500 pF of parallel capacitance and the circuit had a Q factor of 16.

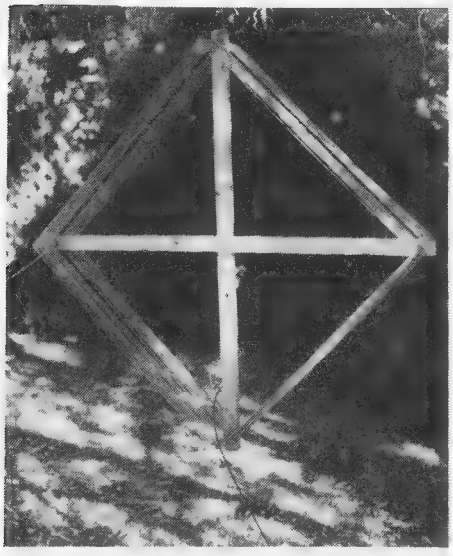


Figure 7: The 20 turn loop aerial wound with shielded wire

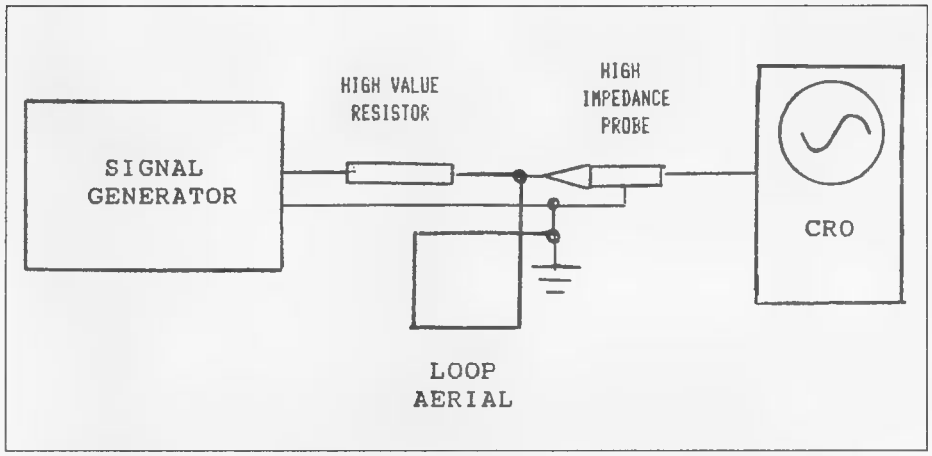


Figure 8: Measurement of loop aerial constants

Clearly, the loop was ideal for this frequency. Below 100 kHz, signal pick up was less than adequate and very large values of capacitance were needed to resonate the loop. This particular loop aerial is clearly a very good form for the MF band but not really suitable for VLF and lower LF. Nevertheless, it was another interesting experiment to find out what would work at the lower frequencies.

Measurement Of Loop Constants

At this point, it might be useful to explain how the loop constants were measured. Having constructed a loop aerial, we need to know its natural resonant frequency and its self inductance so that the maximum tunable frequency can be determined and the capacitance values worked out for the tuning range required. These factors can be measured using a signal generator fed via a fairly high resistance (say 10 k ohms) to the loop as shown in figure 8. More than one signal generator might be needed to tune from VLF to MF. The voltage across the loop is monitored on a CRO (or perhaps a VTVM) via high impedance probe. The signal generator frequency is adjusted for a peak in voltage at which the natural frequency is indicated. We now add a large capacitance (at least 20 nano-farad) sufficient to make the loop capacitance insignificant by comparison and retune for a peak at the new lower frequency. Inductance is then calculated from the normal resonance formula (or a resonance chart), using the parallel capacitance as the formula (or a resonance chart), using the parallel capacitance as the value of C and ignoring the self capacitance of the loop as this makes little difference to the accuracy of calculation.

Having measured the self resonant frequency and calculated the inductance, the loop self capacitance can also then be derived from the resonance formula.

As a further operation, Q factor can be measured using the same equipment except that the resistance in series with the signal generator must be increased to around 100 kohms to prevent the Q being lowered by the signal source. With extra signal loss across the resistor, a high signal level and a sensitive CRO are needed. The procedure is simply to measure the frequencies, either side of resonance which give 0.707 of the voltage at resonance. Q factor is equal to the resonant frequency divided by the difference between the two frequencies recorded. Q factor at a range of frequencies can be carried out by varying the value of the shunt capacitor to obtain resonance at each of the frequencies.

To go one step further, we can now calculate the AC resistance of the loop (Rt) at any frequency for which we have derived Q. The inductive reactance at that frequency is calculated from $2\pi fL$ and the reactance is then divided by Q to obtain Rt. We now know all the constants Rt, L and C, as shown in figure 2.

Performance

Whilst the level of its signal pick up is low compared to the long wire aerial, it has been clearly demonstrated in the writer's experiments that the loop aerial can separate out signals in the presence of localised noise which overrides the signal on the long wire. As with any directional aerial, it also improves the signal to noise ratio for atmospheric noise by restricting noise received, in particular from a direction at right angles to its plane.

Surprisingly, this performance could be achieved with the loop aerial sitting on the cement floor of the writer's shack, which happens to be clad in sheet iron. With a suitably designed loop aerial and a highly selective front end tuning sys-

tem, good signals at VLF and LF can be received indoors, right down to 10 kHz. This is gratifying if one does not have room for an outdoor aerial. Of course there are the odd traps.It is very easy to miss a signal if it happens to arrive from a direction close to the null of the loop. It is also very easy to home in on some inside based signal source such as the writer's frequency counter.

Untuned Loop

Discussion has been centred around loop aerials, tuned to resonance and giving output voltage as in formula (1) or (2) multiplied by Q. However loop aerials can also be operated in a broadband mode and a design procedure for doing this over a range of frequencies is described in April 1989 issue of "Lowdown". The procedure is to load the loop aerial into a fairly low resistance, at the pre-amplifier input, equal in value to the loop inductive reactance at the lowest frequency of the frequency band required. Parallel resonance is set to a frequency calculated from the geometric mean of the lowest and highest frequency required. According to the article, the design produces a loop response which is flat with frequency.

Whilst the broadband loop eliminates the complication of loop tuning when changing frequency, the loss of Q multiplication can drop atmospheric noise below the noise floor of the amplifier thus limiting the sensitivity to weak signals. As an example, if we apply formula (2) to the 12 turn 0.8 metre square loop described and use a typical atmospheric noise for 100 kHz, which can be around 0.2 micro-volts per metre per root hertz, we get a loop output voltage of 3.2 nanovolts per root hertz. This output level is barely comparable with equivalent input noise voltages at low impedance of the best of amplifiers.

Conclusions

A properly designed loop aerial system, with a low noise pre-amplifier, is a useful part of the VLF-LF receiving equipment and can enable signals to be picked out from noise which otherwise overrides the signal from the wire aerial. It also provides a means to obtain good signal reception at VLF-LF without the use of a large aerial installation usually considered necessary for low frequency reception.

The signal level received from the loop aerial is low compared to the wire aerial and the signal to noise ratio can be limited by the noise generated in the first amplifier. To minimise this problem, a low noise pre-amplifier is used and the loop circuit is tuned so that the signal level into the amplifier is multiplied by the Q factor of the loop circuit.

Some experimental loop aerials and a loop tuning and interface circuit have been described. Operated in conjunction with the high Q front end tuner, previously described in "Amateur Radio", they have provided impressive performance when everything is carefully tuned up.

References

1. Direction Finding (Loop Aerials) — Admiralty Handbook of Wireless Telegraphy, Section T.
2. Lloyd Butler VK5BR — Amplifier Noise — Amateur Radio, November 1982.
3. Analysis & Design of Broadband Low Frequency Loops — Lowdown, April & May 1985.
4. Castle, C. H. VK5KL — A 10ft Diameter Receiving Loop on 1.8 MHz — Amateur Radio, March 1982.

Technical Correspondence

Experimental Communications in the LF Band

Several of my recent articles have been concerned with receiving equipment for the VLF-LF bands and this has led to my taking quite an interest in what sort of activity occurs on these bands. There are certainly plenty of enthusiasts interested in listening on the low frequencies but there are also others who actually transmit signals and communicate with each other.

Low frequency experimentation does not seem to get much attention in the Amateur Radio magazines or in the Amateur Radio handbooks but there is an organisation called "the Longwave Club of America" which publishes a journal called "Lowdown". A number of copies of these have been kindly lent to me and they are certainly packed with plenty of low frequency information including transmitters, aerial systems and comprehensive lists of transmitted signals which can be heard on the bands.

The lack of information in amateur radio publications is probably due to the fact that there is no official amateur radio band allocation at the lower frequencies. In the USA, transmission can apparently be carried out in a frequency band between 160 and 190 kHz by any citizen subject to certain FCC rules. These rules specify that the input power to the final transmitting radio frequency stage shall not exceed one watt and that the total length of the transmission line and antenna shall not exceed 15 metres. There does not appear to be any other restrictions, such as mode of transmission, or operating procedure except that emissions outside the band shall be suppressed by 20 dB below the modulated carrier level. One watt input represents a fraction of a watt radiated using the limited length of antenna one would have in the suburban house allotment and in any case, restricted by the rules to 15 metres. Notwithstanding this, experimenters have been able to communicate and have their beacons heard at quite some distance, using this low power.

There has also been low frequency activity on the Australian scene. In "Amateur Radio" July 1984, an article by John Adcock VK3ACA was published on LF experimentation. John describes how he and Peter Forbes VK3QI (and later Dennis Sillette VK3WV) applied for, and were granted, an "experimental Licence" to operate amateur radio type of equipment in the LF band. A frequency of 196 kHz was approved and the article deals with the transmitting and aerial equipment John used on this frequency and some of the results obtained.

Clearly, the input power to the final amplifier was more than one watt (John used a pair of 6JS6S in the final) and signals from Melbourne were heard as far away as north of Newcastle and in the Flinders Ranges.

The question is whether there is any of this LF communications activity still going on in Australia today. Perhaps someone can provide some further information on this question.

Lloyd Butler VK5BR
18 Ottawa Ave
Panorama 5041

ar

Support the WIA in order to protect amateur radio frequencies at WARC 92.

EXPERIMENTAL STATIONS ON 196 kHz 1531 METRES

John Adcock, VK3ACA
12 Albert Street, Oak Park, Vic 3046

The salient points of a lecture given on the subject "Amateur Radio and Low Frequencies" at the WIA Victorian Division meeting in November were presented by Jim Linton in January Amateur Radio. I propose here to present some details of the experiments so that they are recorded for posterity.

I do not intend to push the idea of amateurs on long waves. I think some amateurs will be motivated with considerable interest in the subject while others will barely give it a passing thought. It happens to be a subject I have had some interest in. Also I have always been of the opinion that amateur radio should have a representative part of the whole radio spectrum.

Some people have asked me. *"Why bother transmitting on these frequencies when you can listen for non directional beacons on nearby frequencies to observe propagation conditions?"*. The reason is the same as why we operate amateur radio. There is nothing like first hand experience. Not only that, it is difficult to get a clear idea of things from beacons because there are many operating on the same frequency.

Operating on long wave is certainly not new. Trans Atlantic transmissions were carried out on long wave before the discovery of long distance propagation on short wave. Long waves are still used for world wide radio communications. There are broadcast stations in Europe and Asia between 150 and 350 kHz and these are audible in Australia from time to time.

Early amateurs used long waves but probably not since 1910, except by accident. There has been a very long standing agreement by authorities that amateurs can only use "wavelengths shorter than 200 metres" (frequencies above 1500 kHz). This was stated even on pre "First World War" licences and is also referred to in the ARRL Handbook. To me, the broadcast band has appeared as a barrier which must never be crossed. I won't say that the grass is greener on the other side but it is certainly interesting.

HOW IT CAME ABOUT

For some time past, the Americans have had the use of a citizens allocation of frequencies (no licence required) between 160 and 190 kHz. According to "CQ Magazine" the band was allocated for the purpose of opening garage doors. The power allowed in this band was very limited. Prior to WARC 79 there were several proposals for an LF band from America and several other places. Unfortunately for many and varied reasons these proposals were withdrawn prior to the WARC conference.

Originally the WIA were prepared to support the ARRL with their proposals and the matter was discussed with the department. I learned from members of the committee that, since the American withdrawal, the proposal was now in abeyance but the department may consider applications for an experimental licence.

What is an experimental licence? The department have always issued experimental licences for specific purposes. There are no specific rules about obtaining one. To obtain an experimental licence you have to write to the department stating what you intend to do, why you intend to do it, what equipment you intend to use and your qualifications. Having heard of this possibility I determined to follow the matter up.

The proposal that I put to the department was I would like an experimental licence to operate on a low frequency in the region of 1.60 to 200 kHz, CW telegraphy only, using amateur radio type equipment only and a backyard antenna. I would communicate with one other person with similar interest. The other person interested was Peter Forbes VK3QI and we both sent in our applications together.

In preparing the application it was considered necessary to make a reasonable proposal which had a chance of being accepted. For example CW occupies a minimum of spectrum space in a band with very little spectrum.

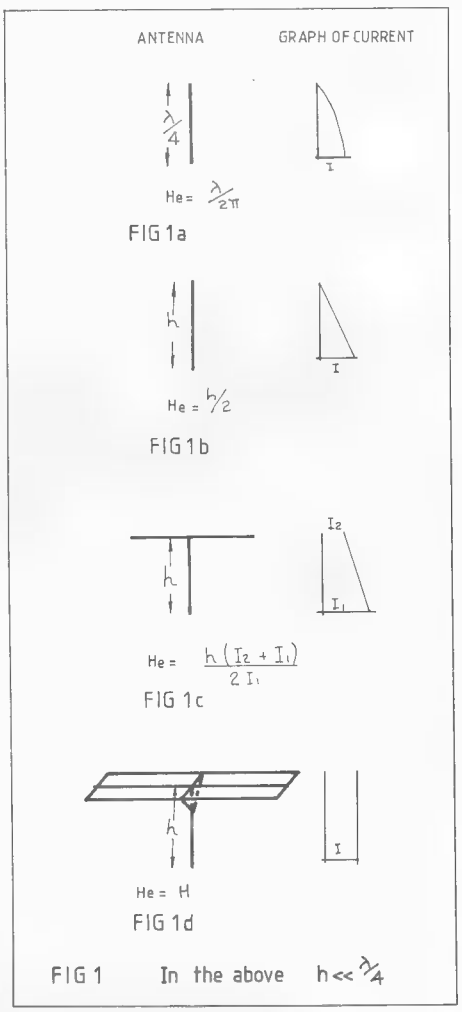
The proposal was eventually agreed to and licences granted. The frequency allocated was 196 kHz for CW telegraphy with a frequency stability of +/- 200 PPM and a channel width of 100 Hz. The callsigns were AX3T35 to J Adcock and AX3T36 to P Forbes. The licences were dated from 17th March, 1981. The frequency stability requirement is relatively easy to achieve; the channel width requirement meant that key clicks had to be eliminated. Ask any old timer how they went about building a key click filter.

In the following paragraphs I intend to give an outline of technical requirements on LF and how we achieved these requirements. As regards LF propagation I find this is not covered at all in amateur radio texts. One of the most widespread misconceptions is that LF propagation is by groundwave only. Not so! Low frequencies are reflected by the ionosphere in a completely different manner to that on HF. The propagation improves below about 300 kHz and peaks about 12 kHz. I propose to detail LF propagation characteristics in a later article.

THE ANTENNA

The polarisation of a low frequency signal at ground level is effectively vertical. This statement will be qualified later. The height of any practical low frequency antenna must of necessity be small as compared with a resonant length. The antenna must be vertically polarised and should be physically as large as practical limits will allow. In fact an LF antenna cannot be too large! They have very large top loads, usually much larger than the vertical section and have some form of elaborate ground system. The following is a brief theory as applied to low frequency antennas.

All antennas can be considered to consist of two parts. The ends of the antenna mainly carry voltage and originate the electric or "e" field; the centre of the antenna mainly carries current and originates the magnetic field or "h" field. Because of the relative smallness of an LF antenna it is advantageous to concentrate the current in the veritcal section of the antenna and concentrate the voltage at the



top load. In antenna theory it is usual to base all calculations on the current part of the antenna only, but one must not lose sight of the fact that the "electro magnetic field" consists of two fields originating from the two parts of the antenna.

Fig 1a shows the graph of current distribution on a quarter wave vertical which is in fact of sinusoidal form. The current distribution on a much shorter antenna will be represented by only a short section of the quarter wave antenna and since the graph of current distribution is only a small section of a sine wave it can be regarded as a straight line. There are three main examples of current distribution on such an antenna. A vertical with no top load is shown in fig 1b, a vertical with a relatively small top load fig 1c and a vertical with a large top load fig 1d. A current distribution of the form shown in fig 1d is the one to aim at. For more detail on this subject refer to an earlier article by the author ref 1.

In the following discussion it can be assumed that the word "antenna" refers to an antenna which is very short as compared with a quarter wave such as used at LF. The power radiated from an antenna is proportional to both the square of the current and the square of the effective height (ie the effective length of the current carrying element). It is therefore obvious that both these quantities must be as large as possible. The components of a short antenna when measured on an impedance bridge in series with the ground are capacitive and resistive. The equivalent circuit is usually considered as a series circuit. The series resistance part of the circuit is made up of two parts, loss resistance and the component due to radiation usually called "radiation resistance". The radiation resistance of an antenna is given by the formula —

$$Rr = \frac{1580\ He^2}{\lambda^2}$$

where He = effective height and λ = wave length, both in the same units. The effective height is given in fig 1 in each case. The power radiated from the antenna is given by —

$$Pr = I^2Rr$$

To illustrate the significance of these formulae we will look at their practical application in the next section.

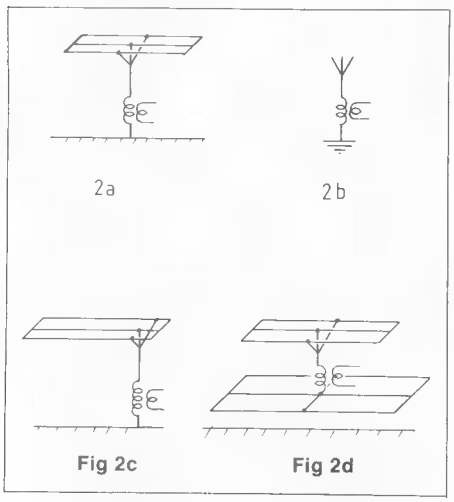


Fig 2c

Fig 2d

The most common concept of an LF antenna are shown in fig 2a. In fact this antenna is the one from which the antenna symbol came fig 2b. It makes use of a large top load. The load must be large to have a large capacitance while still having a good height above the ground. The antenna fig 2a is classically known as the "Tee"; another arrangement shown in fig 2c is known as the "inverted L". The antenna, which is mainly capacitive, is tuned by means of a series loading coil coupled to the transmitter. It cannot be emphasised too often that such an antenna is very inefficient. The radiation resistance is very low, the capacitive and inductive reactances are high, the coil loss resistance is high and the ground resistance is high. The ground resistance can be reduced by using buried radials or by using a counterpoise as in fig 2d. There are a most bewildering variety of designs of top load, earth system and counterpoises and it is not intended to discuss their details here. The reader should refer to the many texts on the subject.

THE ACTUAL ANTENNA

In this section it is proposed to detail the antenna that is used by AX3T35 in Oak Park and particularly illustrate the difficulty in obtaining even a moderate efficiency.

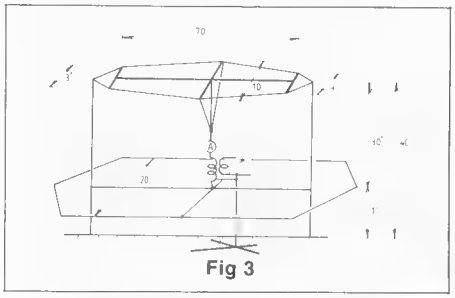


Fig 3

The construction of the antenna is shown in fig 3. Several variations of the antenna were tried but for simplicity we will consider only the one shown. The loading coil (in long wave stations is called the helix) is shown in the photograph fig 4. It consists of seventy turns of 10 B&S enamelled wire wound on a fibreglass former 0.5 m (20") diameter. Before winding such a coil I suggest you make sure you can borrow a large lathe. The former was made by laying fibreglass over the cardboard concrete form tube. The coil was broken in the centre with a three turn rotating link in variometer fashion for fine tuning. Coarse tuning was carried out by taps at the end of the coil.

The coax from the transmitter was coupled to the loading coil with a single turn link. In the final arrangement the earth was tapped onto the coil so as to combine the effect of the earth and counterpoise to best advantage.

To simplify calculations we will assume that the vertical section of the antenna is 30 ft long, carries the same current top to bottom and is not connected to ground. The measured capacitance of the top section was 333 pF and that of the counterpoise was 585 pF. From capacitors in series —

$1/C = 1/C1 + 1/C2$

$C = 213$ pF

This is effectively the capacitance loaded across the coil. The capacitive reactance at 196 kHz is —

$Xc = 1/2\pi fC$

$Xc = 3812$ ohms

To resonate the system the coil must have the same reactance. Therefore to obtain inductance of coil —

$L = X1/2\pi f$

$L = 3095\ \mu H$

From the formula for radiation resistance —

$Rr = 1580\ He/\lambda$

$He = 30$ ft or 9.1 metres

λ at 196 kHz = 1531 metres

$Rr = 0.056$ ohm

The measured Q of the coil was 400; actually a very good Q. The effective series resistance of such a coil is given by —

$R = X/Q$

$R = 3812/400$

$R = 7.96$ ohm

It is now obvious why it is so difficult to obtain a reasonable efficiency. If the loss resistance is 7.96 ohm and the radiation resistance is .056 ohm the efficiency can't be better than 0.70 percent. The coil resistance loss is not the only loss.

Consider the following, if the aerial circuit was 100 percent efficient with 100 watts to the circuit the aerial current would be —

$I =$

$I = 42$ amps

The voltage on the top load of the antenna with respect to ground is given by —

$Xc = 1/2\pi$ f0 where c = 333

$Xc = 2438$

$V = XcxI$

$V = 2438x42$

$V = 102$ kV

Such current and voltage is enormous. The actual antenna current was 2.6 amps. The radiated power would be —

$W = I^2R$

$W = 2.6^2 \times .056$

$W = 0.38$ watt

Since the power to the antenna is 100 watts, the efficiency is 0.38 percent. The voltage on this antenna would be 6.3 kV.

Since the actual efficiency is .38 percent it is obvious the coil loss is not the only loss. Other losses are, resistance in the antenna and ground (if connected), induced losses in surrounding objects and leakage across insulators.

How do you reduce these colossal losses? Unfortunately there is only one way, by making the antenna bigger! For example the radiated power goes up in proportion to the

square of the effective height for the same antenna current. A wider longer topload has a higher capacitance, the coil will need less turns and therefore less resistance and more current. The radiated power is proportional to the square of the current. If the antenna was doubled in all dimensions the efficiency could be raised from .38 percent to six percent.

A USEFUL NOTE

Two items I found very useful in constructing the equipment described were a "Q" meter and a small coil winding machine. A "Q" meter can be used to measure resonate frequency, inductance and circuit loss. The "Q" meter used was a very old instrument by Advance. The coil winding machine was a small device available about ten years ago for $10. However it is quite adequate for all honeycomb coils.

THE TRANSMITTERS USED BY AX3T35 AND AX3T36

The transmitter used by AX3T35 was conventional. It consisted of a 6CL6 oscillator 5763 buffer and a pair of 6CD6GAs in parallel in the final. The oscillator buffer section was originally a Geloso 4/104 VFO. The only parts of the original VFO used was the chasis, the dial and the valve sockets; the rest was new.

The transmitter was originally VFO controlled but was later changed to crystal. The oscillator and buffer coils were home wound. The final tank circuit used an AT5 MF section variometer transmitter tank coil tuned by fixed mica capacitors. At LF variable inductor tuning is often simpler than variable capacitor tuning. The circuit of the transmitter tank section is shown in fig 5.

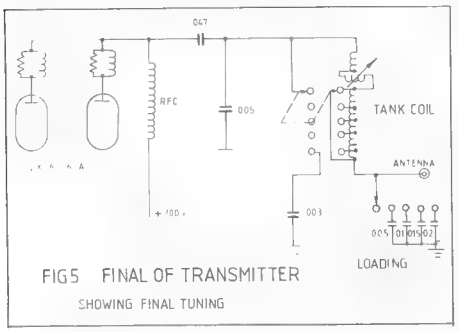


FIG5 FINAL OF TRANSMITTER
SHOWING FINAL TUNING

The transmitter used by AX3T36 was a transverter modelled around an FT101 and used a pair of 6JS6s in parallel in the final. Conversion was from 7 MHz.

When we talk about large inductances many think of ferrites, it is therefore advisable to make some reference to these. Peter Forbes successfully used some ferrites in his transverter. The constructor must always calculate the likely flux density in the core to ensure saturation is not reached. It should also be noted that on low frequencies the ferrite is likely to turn out larger than expected. I would advise anyone on this subject not to guess at the size of the ferrite or the number of turns but to refer to a reliable text. The largest inductor in the system is the antenna loading coil. It has a much higher "Reactive Volt Amp" rating than any other coil and its efficiency directly affects the overall loss. It is possible to wind a coil with a higher Q than a ferrite, it is therefore advisable that the loading coil should be air cored.

OSCILLATORS

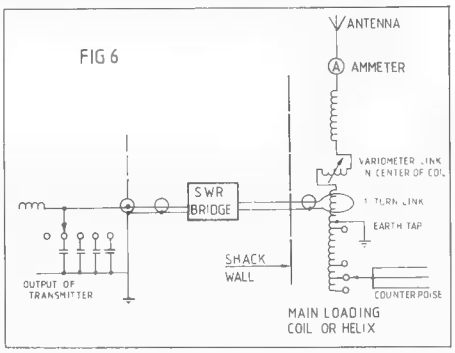
A Colpitts VFO was originally used by the author because it was not known what frequency would be allocated. Although it is possible to obtain good stability with a VFO at these frequencies it is always a nuisance because it is necessary to regularly check the frequency. One way round this problem would be to use a frequency counter. Since the author did not have such a device crystal control was a necessity.

A 196 kHz crystal was duly obtained. A 196 kHz crystal is usually a CD cut and oscillates in a width mode instead of the usual thickness mode. If you plug such a crystal into an HF crystal socket it will oscillate at a high frequency. To make the crystal oscillate in the correct mode it is necessary to use a correct series choke. A very good article on this subject was published by John Foster and Bob Rankin (ref 2).

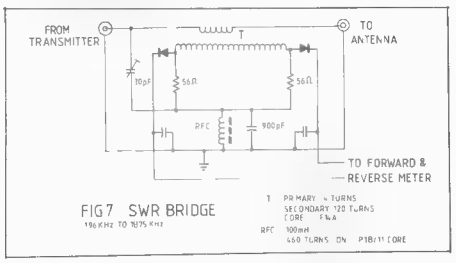
Probably a cheaper and more modern approach would be to use an HF crystal followed by a frequency divider.

FEEDING THE ANTENNA

The output or loading capacitor of the pi tank circuit consisted of a set of fixed capacitors selected by a rotary switch fig 5. The output was connected to a link on the loading coil through a 50 ohm coax and an SWR bridge fig 6.



The SWR bridge is based on a design in the ARRL handbook but using a larger number of turns on the toroid and larger capacitors to suit the lower frequency. When tested on a 50 ohm dummy load the bridge worked satisfactorily from 196 kHz to 1875 kHz.



The loading coil was tuned to give maximum antenna current first by adjusting the taps and then fine tuning with the variometer coil. The earth was tapped just below the neutral point on the coil so that it was partially in parallel with the counterpoise. The maximum antenna current should coincide with minimum SWR. To produce an SWR of nearly 1:1 it is necessary to vary the coupling of the link. In the case described it was found that a low SWR was obtained with a one turn link only. The loading on the transmitter is adjustable by the loading capacitor selector of the pi tank circuit. When tuning a system like this it may be necessary to repeat the tuning procedure several times.

The low frequency section of the AT5 aerial tuning unit was used as a standby tuning unit although it did not have as high an efficiency as the large coil. These units were very cheap and easily obtained once. There should still be some around.

THE RECEIVER

The following comments apply equally to converters and transverters. To minimise images it is best to use a high frequency IF. Peter Forbes used 7 MHz with his transverter: the author used a 5.8535 MHz xtal frequency which is the zero frequency in an FRDX400 tunable IF.

Even when using a high frequency IF, images and cross modulation from the broadcast band are a great problem. Old disposal receivers such as the AR7 and the BC348 perform very well on these frequencies. Modern all band amateur type receivers tend to suffer from front end overload and are not usually optimised on LF. These receivers are also greatly improved by using antenna tuning. There are a few disposal receivers around which are designed for these frequencies and these are ideal.

The transmitter antenna tuning was used for receiving but it covered a rather limited frequency range. The AT5 ATU was found to be excellent for general listening.

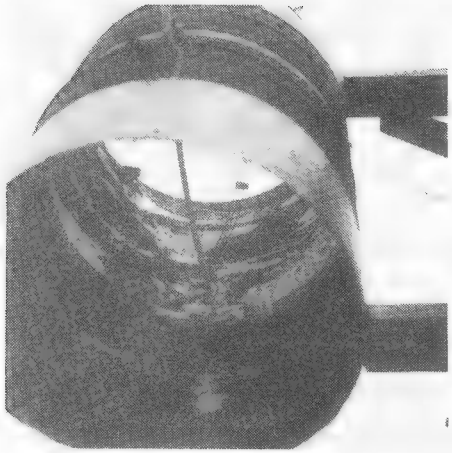
On a receiver that is working properly it should be possible to hear non directional beacons every 3 kHz from 200 kHz up to 415 kHz. In most cases several NDBs can be heard on one frequency. Between 100 kHz and 200 kHz there are no strong signals but there are teletypes and a number of nondescript signals to be heard. Siberian broadcast stations can sometimes be heard at night. Loran, which sounds like the woodpecker, can be heard at night between 90 and 110 kHz. If you cannot hear these signals I suggest you look at your receiver and antenna tuning otherwise you won't have much chance of hearing amateur experimental stations.

PROPAGATION

It is intended to make this the subject of a separate article, therefore only a brief description is given here. Sky waves are reflected from the boundary between the atmosphere and the bottom of the ionosphere in the same way as waves are reflected by the ground. At low frequencies ground waves travel much further than at HF, low angle sky wave reflection is much better than high angle, sky wave propagation is better at night than day. Below about 300 kHz sky wave reflection improves with decreasing frequency and reaches a peak of efficiency about 12 kHz. The ground wave is dominant to about 400 to 500 km distance from the transmitter where the sky wave takes over for longer distances.

RESULTS

On 31st May, 1981 two way communications were established between AX3T35 at Oak Park (Melbourne) and AX3T36 at Lake Boga. Since then Dennis Sillette VK3WV was issued the call VL3Y and has also been worked by



Inside view of the loading coil.

AX3T35. AX3T35 has been copied in Mount Gambier, Stawell, Stratford, Hobart and many places in between during the day. At night the signals have been copied north of Newcastle and in the Flinders Ranges. In general, reception is better in the ground wave range during the day because of lower static.

I must mention that a number of people have listened for the signal and have not heard it. In the areas from which reports have been received there has been a big variation in individual strength and readability reports. I put this result down to different receiving conditions at different stations. At the moment I do not believe I have achieved best efficiency of radiation from my backyard nor has the maximum receiving range been achieved. In this type of work anyone with a small farm would be at a great advantage.

I would like to thank the many people who sent in reports.

REFERENCES

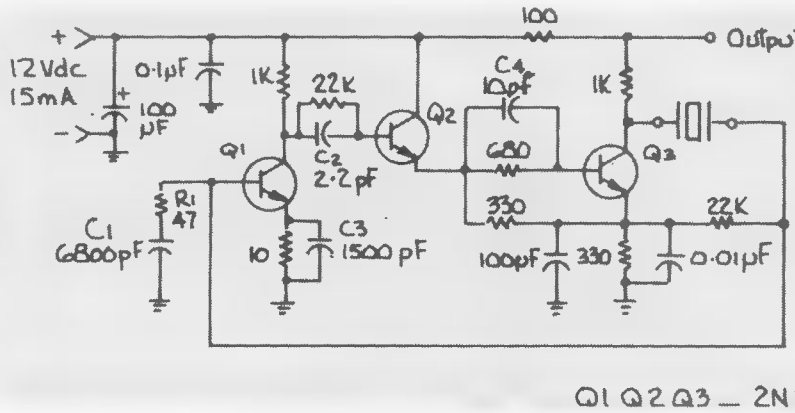
Reference 1. Home Station Antenna on 160 metres. Amateur Radio June 1971

Reference 2. Quartz Crystal Oscillator Circuits, Electronics Australia November 1972

AR

TRY THIS

CRYSTAL OSCILLATOR WORKS AT 1 kHz to 10 MHz



Circuit of a transistor universal oscillator works for any crystal at 1 kHz to 10 MHz. Even through the four-decade range, the circuit needs no adjustment.

A universal crystal oscillator that operates over a four-decade range — 1 kHz to 10 MHz — needs no adjustment for such a wide disparity in frequency and produces an output at or near the crystal's series resonant frequency.

As shown in the figure, three transistors are connected as a direct-coupled video amplifier with negative DC feedback. The crystal is connected in the positive feedback path from the collector of transistor Q_3 to the base of transistor Q_1. Because high-frequency crystals have a lower series resistance than low-frequency ones, the series combination of resistor R_1 and capacitor C_1 is used to attenuate feedback at the high frequencies. This combination also reduces feedback resulting from the crystal's shunt capacitance.

High-frequency peaking is accomplished with capacitors C_2, C_3, and C_4. Although the frequency range can be increased with more peaking, doing so invites spurious oscillations when low-frequency crystals, with their high shunt capacitance, are used.

The circuit produces about 7 V pk-pk in the form of a square wave for low frequencies. For best operation, components with tolerances of 5 percent or better should be used.

Fred Brown, Consulting Engineer, PO Box 2053, Rancho Santa Fe, Calif, 92067.

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AR

A FERRITE ROD LOOP AERIAL FOR VLF

LLOYD BUTLER VK5BR
18 OTTAWA AVE
PANORAMA 5041

In a previous article (reference 1), I made comparisons between the performance at 1.8 MHz of the ferrite rod loop aerial and open frame loop aerials. Experiments were carried out using a ferrite rod 20cm long by 9.5mm diameter and open loops 0.8m square. Generally speaking, the open loop aerials performed with signal sensitivity considerably better than the ferrite loop aerial. However, at frequencies below 100 kHz, I was able to achieve results which were essentially the reverse.

By winding 1540 turns on the ferrite rod in several pies, an inductance of more than 100 millihenries was obtained with the low distributed capacitance of around 50 pF. Using a 15 to 450 pF x 2 gang variable capacitor and a switchable 100 pF fixed capacitor, a tuning range of 11 to 52 kHz was achieved. Higher frequency tuning was made possible by tapping down to junctions between the pies. The large number of turns used at the low frequencies provided a considerable advantage and, below 100 kHz, the signal sensitivity was found to be as much as 10 dB better than an open loop aerial with which it was compared.

More detail on the ferrite rod loop aerial and the comparison open loop is given in the paragraphs which follow.

Detail of the Loops

The ferrite rod was overwound with two pies of 600 turns and one each of 240 turns and 100 turns as shown in figure 1. The pies were wound in a criss-cross pattern to reduce capacitance between individual turns, and this formed a winding shape similar to that shown in the diagram. Machine-wound honeycomb-formed pies would have been better had one of these machines been available.

The diagram (figure 2) shows the loop switching and tuning circuit and its connection via the interface amplifier. Combined with the two paralleled sections of the tuning gang capacitor, the series connection of all pie windings is tunable between 15.5 and 52 kHz. Tuning is extended down further to 11 kHz by switching in a 1000-pF capacitor across the circuit. Higher frequencies are tuned by switching out one or more of the pies. Q factor of the ferrite loop measured reasonably high at the lower frequencies. At 20 kHz it was 25.

The amplifier is the same as that previously described for VLF-LF loops (reference 2) except that the two resistors at the amplifier input have been increased in value to one megohm. This was necessary because of the higher value of inductance in the ferrite loop aerial, the consequent higher parallel impedance at resonance and the necessity to make the amplifier input resistance high by comparison so that it does not greatly lower the circuit Q.

The open loop aerial, used for comparison, was made up of 20 turns of wire spaced laterally apart by 1cm on a 0.8m square frame. A similar 20-turn loop aerial was described in reference 2, but the shielded wire in this was replaced by a heavier gauge of unshielded wire with 1.1mm diameter conductor. Without shielding, self resonance was increased to 750 kHz as compared to 100 kHz achieved with the shielded wire. This allowed tuning the full range of 10 to 500 kHz without tapping down loop turns. Of course, with only 500 microhenries of inductance, this loop had been tuned with large values of capacitance switched in as described in reference 2. The heavier gauge wire also increased the Q factor which measured 20 at 20 kHz.

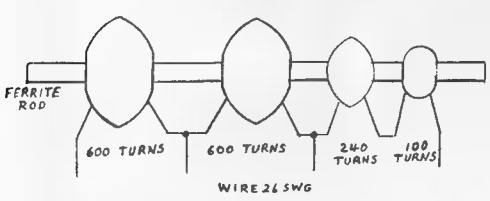

Figure 1 Layout of Ferrite Loop Aerial Windings

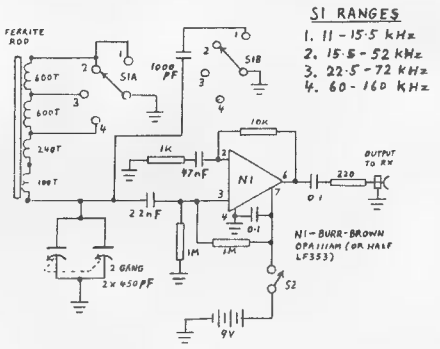

Figure 2 Ferrite Loop Switching, Tuning and Interface Amplifier

Loop Shielding

One thing that is very noticeable about the ferrite loop aerial at these low frequencies is its high sensitivity to noise pickup from nearby mains cables. This is possibly aggravated by the higher impedance of the loop circuit which makes it more sensitive to electrostatic pickup. Those who have had audio frequency experience with high impedance valve grid circuits, working at low levels, will recognise the need for shielding from the mains leads and other stray noise. The lower VLF extends into the upper audio range and, similarly, electrostatic shielding of the high impedance ferrite loop circuit, including tuning components, is also essential. The loop aerial itself requires a special form of shield which does not act as a short circuit around the loop, restricting magnetic induction into its windings. Figure 3 is a sketch of an open-ended aluminium box which was built as a shield around the aerial under discussion. Observe that one edge of its lid is electrically isolated from the side of the box by insulating spacers.

Even with shielding, the ferrite loop still picks up some noise, and I found it necessary to operate the aerial at least one metre away from any power wiring.

Comparison of Performance

Signal sensitivity (or the ratio of output volts to field strength in volts per metre) for the 20-turn open loop was calculated from the loop formula to be a value of 0.1 at 20 kHz. Signal sensitivity for the ferrite loop was difficult to determine from calculation. Two of the variables in the formula are the corrected permeability and the area (and hence the diameter) of the turns. With the method of winding used, the value of corrected permeability was not clearly defined, and the diameter of turns varied from one centimetre at the centre of a pie to 3.5 cm at the outside. However, using some averaging and a little guesswork, it ap-

peared that, with all windings in circuit, the ferrite loop should be at least equal to, or more sensitive than, the 20-turn open loop. In practice, this proved to be correct, and, at VLF, the ferrite loop was found to have a sensitivity advantage. At 43 kHz, the two loops had much the same sensitivity. At Omega frequencies (around 12 kHz) the ferrite loop produced a signal level about 10 dB greater than the open loop.

Whilst the ferrite loop is quite sensitive at VLF and the lower part of the LF spectrum, its sensitivity falls off as turns are tapped down to enable tuning to higher frequencies. In fact, with only the 100 turn pie in circuit to tune up to 500 kHz, I had great difficulty in detecting the strongest of NDB stations. In consequence, the 100-turn junction was not connected into the loop switching circuit, which is shown in figure 2.

Apart from its higher sensitivity at VLF, the ferrite loop has an advantage over the open frame loop in size and portability. On the other hand, the open loop is less prone to pickup of localised noise, and I have found that, even if less sensitive, it gives a better signal-to-noise ratio in the presence of such noise.

Conclusions

By using appropriate windings as discussed, the ferrite rod loop aerial can be made to operate with high signal sensitivity in the VLF spectrum. Furthermore, the values of self inductance and capacitance are such that the loop can be tuned over the VLF range of frequencies with an ordinary receiver variable tuning gang capacitor.

Whilst the sample ferrite loop aerial has been found to be more sensitive at VLF than a typical open frame loop aerial, it is inclined to pick up more noise, and its good performance is not maintained above 100 kHz.

In concluding this third article on receiving loop aerials, I must add that these aerials are an interesting field of experimentation which can be carried out with simple materials and minimal cost. Furthermore, they require only limited space and, in fact, operate quite well indoors.

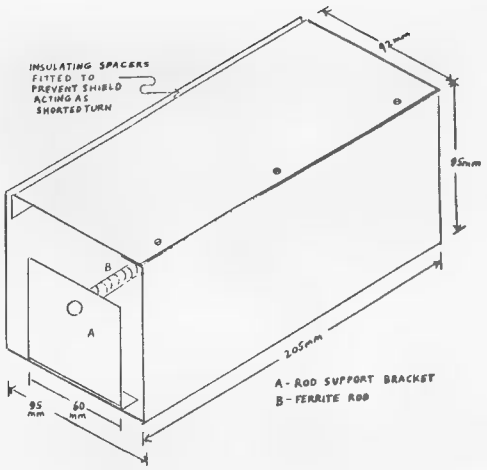

Figure 3 Ferrite Loop Aerial Shield

References

1. Lloyd Butler VK5BR, Receiving Loop Aerials for 1.8 MHz, *Amateur Radio*, September 1990 p10.
2. Lloyd Butler VK5BR, VLF/LF and the Loop Aerial, *Amateur Radio*, August 1990 p12.

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A Bandwidth Limiting LF Up Converter for Frequencies Around 200 kHz

Lloyd Butler VK5BR has a different approach to Low Frequency converter design, and it works!*

Introduction

Over recent years a few radio amateurs have ventured into experimental communications at frequencies around 200 kHz. Not many amateurs have receiving equipment for such low frequencies, and some might attempt building an LF up converter to operate in conjunction with their higher frequency receiver. The one I am about to describe is a little different from the usual design, and I must first introduce reasons for that difference.

I refer you to experimental CW transmissions on 196 kHz carried out by John Adcock VK3ACA and Don Bainbridge VK3BDJ at Gordon, Victoria. I monitored, in Adelaide, the 6th June 1992 tests, and the results obtained illustrate the points I wish to make. Using a receiver in a wide-band mode and connected to a long wire antenna, the signals were barely discernible amidst the inherent band noise. However, I was able to resolve these almost noise free with the following:

(1) *Limiting the receiver bandwidth* — As the CW signal is a narrow band mode, the noise bandwidth can also be reduced to no more than that required for reproduction of the signal.

(2) *Use of a tuned loop antenna* — The loop is less susceptible than the long wire to pick up of near-field noise. Its directional properties also enhance its ability to improve the signal-to-noise ratio (see Reference 1).

(3) *Use of a sharp audio filter* — As a single audio frequency keyed tone is produced by the receiver beat oscillator, audio bandwidth can also be limited to further reduce the noise.

If one adds an LF converter to an existing receiver, the first requirement to limit the bandwidth might be satisfied if the receiver has a crystal filter. Many receivers have such a filter fitted in the 455 kHz IF chain, but what do we do if no such filter is installed? One might consider making modifications to the receiver, but this could prove to be difficult or messy. The question I am raising is how bandwidth limiting might be achieved in the add-on converter circuit itself. At VLF (say 20 kHz) this can easily be achieved in the front end using a high Q circuit. For example, at 20 kHz a tuned circuit with a Q of 100 has a 3 dB bandwidth of only 200 Hz, which is suitable for the narrow band signal. However, at 200 kHz, the same Q of 100 gives 2000 Hz bandwidth, too wide for our purpose. So, at 200 kHz, we need some other means of narrowing the bandwidth, and this has led to the particular LF converter design which I will discuss.

A Different Arrangement

The usual form of LF up converter is shown in figure 1. The LF signal is mixed with a fixed frequency oscillator (usually crystal locked) to produce a higher first intermediate frequency at which the front end of the receiver is set. The incoming LF frequency is selected by tuning the receiver frequency to provide, in effect, a variable first intermediate frequency.

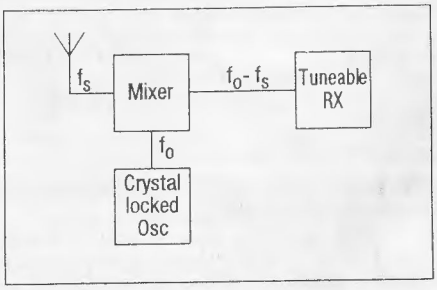

Figure 1 — Usual form of converter.

To achieve bandwidth limiting, I have rearranged the conversion circuit so that the oscillator is variable and the first intermediate frequency (or receiver input frequency) is fixed, allowing the insertion of a crystal filter at that fixed frequency (the changed arrangement is shown in figure 2). The incoming LF frequency is now selected by tuning the oscillator instead of the receiver. To satisfy the second requirement listed earlier, the tuned front end also incorporates a loop antenna.

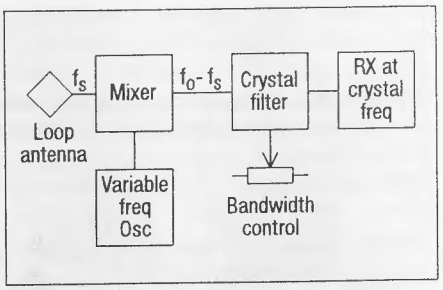

Figure 2 — Converter re-arrangement to limit bandwidth.

Choice of Crystal Frequency

My original idea was to convert up to 3.5 MHz and make use of a crystal around this frequency. Most radio amateurs would have a transceiver which operates on 3.5 MHz even if they have nothing else. However, tests on a crystal filter using crystals around this frequency produced bandwidths around 400-600 Hz. I thought this was too wide, and finished up using a crystal of 1.5 MHz, which produced a bandwidth of around 200-250 Hz. Of course, the precise frequency is not important, but I happened to have a crystal on 1.5 MHz which sits right at the end of the broadcast band. One might prefer to use a crystal on the amateur band at 1.8 MHz, and this could be expected to produce a somewhat similar bandwidth. In any case, the bandwidth varies a little with the Q of individual crystals.

The Circuit

The circuit of the LF converter, less the variable frequency oscillator (VFO), is shown in figure 3. A loop antenna as specified forms the inductance for input tuning at LF. This operates indoors and is connected to the tuning capacitor and interface amplifier via 150 cm of RG58 coaxial cable. The loop tunes between 180 and 370 kHz, using a three-gang 10 to 450 pF tuning capacitor with its three sections paralleled. The tuning range can be extended down to 150 kHz by switching in parallel a fixed capacitor of 470 pF. The length of the cable can be increased with some reduction in the upper frequency limit due to the increased residual capacity caused by the cable. As discussed in the introduction, the loop antenna helps to further improve the signal to noise ratio.

The LF353 JFET operational amplifier package N1 interfaces the loop and the mixer stage. The high impedance input of N1A prevents loading of the loop and the stage provides RF gain. The low impedance output of follower stage N1B drives the mixer stage V1, V2.

The amplified LF signal is mixed with the output of the VFO in the balanced mixer stage. The balanced form of mixer is considered desirable

"The tuning range can be extended down to 150 kHz . . ."

to prevent any significant level of VFO signal from reaching the receiver. The receiver input circuits might otherwise be not able to attenuate sufficiently the VFO signal which is only 150-370 kHz above the 1.5 MHz intermediate frequency. The discrete component balanced mixer using MPF131 transistors was used simply because I had a card already wired up but discarded from a previous project. Otherwise I might have considered using a balanced modulator package such as the MC1496. The balanced mixer shown incorporates a balancing potentiometer RV1. This is set for minimum VFO level at the secondary of T2.

The output from the mixer is fed via crystal filter T3-X1 etc. Potentiometer RV2 controls the bandwidth of the circuit. When the potentiometer is at maximum resistance, it has little effect on the performance of the crystal and the bandwidth is set to its minimum value by the characteristics of the filter. At minimum resistance, the crystal is shorted out and the bandwidth is set by the loop antenna Q in conjunction with the receiver inherent bandwidth. By adjusting the setting of the potentiometer, a bandwidth can be selected as desired between the two conditions. For better spread of adjustment, a logarithmic potentiometer is used. This must be connected for maximum resistance when set fully clockwise.

Trimmer capacitor C10 balances out the crystal holder capacity so that the crystal operates in a series resonant mode. The setting of C10 depends on the style of crystal unit. An easy way to set C10 is to tune the

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LF converter/receiver to a frequency where only noise is received. With RV2 set for minimum bandwidth, C10 is adjusted for minimum noise as indicated on the receiver S meter, or as heard in the speaker.

The crystal filter output is fed to the receiver input via interface emitter follower stage V3. The connection between converter and receiver is shielded to prevent pickup of signals direct into the receiver. The converter cannot be used with a receiver which incorporates a loop stick in its front-end tuning. The loop stick does a fine job of picking up signals in its own right and, of course, must be switched out to prevent interference from those signals. The receiver I used had a loop stick on the broadcast band, but fortunately the next band with standard coils also extended to 1.5 MHz.

The VFO

To tune the LF range of 150-370 kHz, the VFO must be tunable between 1.65 and 1.87 MHz. For best performance of the balanced mixer used, the output of the VFO needed to be in the order of several volts peak to peak. In tuning the VFO, its frequency has to be set quite accurately because of the limiting bandwidth of the crystal filter. The tuning control must therefore be coupled to a good vernier reduction drive and the oscillator frequency must be reasonably stable.

As it happened, I had a VFO ready-made for another project that was put aside, and it was only a matter of changing the frequency range of the tuning. The circuit as shown in figure 4 was based on a design originally published in Break-in. Rob Gurr

"The multitude of NDB stations above 200 kHz . . . provides plenty of test signals . . ."

VK5RG introduced me to the circuit some years ago and, as it seemed to work quite well, I have used it on several projects. The circuit, complete with buffer stages and low pass filter, is probably more elaborate than we need, and I would envisage introducing a simpler circuit later on to do the job. In the meantime, the VFO has provided a stable frequency output at a level of around five volts peak to peak, and has done its job to verify the merits of the system.

Circuit Simplification

At this stage I see some scope for simplification of both the mixer and the VFO circuitry. An attractive option is to make use of balanced mixer type NE602, which has appeared in receiver circuits published in overseas journals. The NE602 appears to do the same job as the well known balanced mixer type MC1496, but does so without all the external resistors required to make the latter work. Furthermore, it has an inbuilt oscillator circuit which can be made to operate by the addition of an external tuned circuit or crystal.

Operation

In setting up the receiver, it is first tuned as close as possible to 1.5 MHz as indicated by the receiver calibration. A distant non-directional beacon (NDB) is tuned in by the converter and the receiver is then finely tuned for maximum signal, preferably indicated on an S meter, if fitted. The signal can be located with the crystal filter set for wideband, but it is important that final adjustment be made with minimum bandwidth.

Tuning of the loop antenna is fairly sharp and must be set for maximum signal. Manual adjustment of tracking between the loop tuning and the VFO tuning is simplified if both tuning dials are calibrated. Some misleading

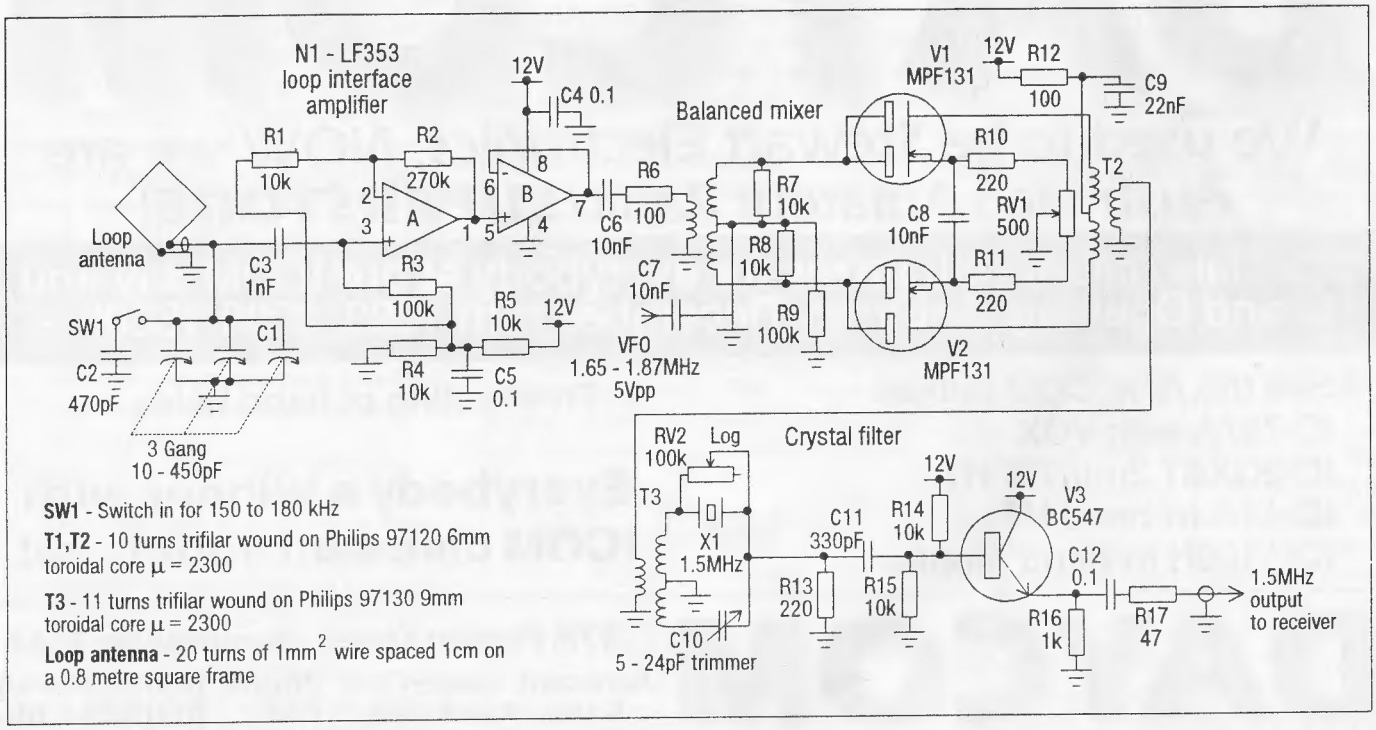

Figure 3 — Bandwidth limiting LF converter, 150-370 kHz.

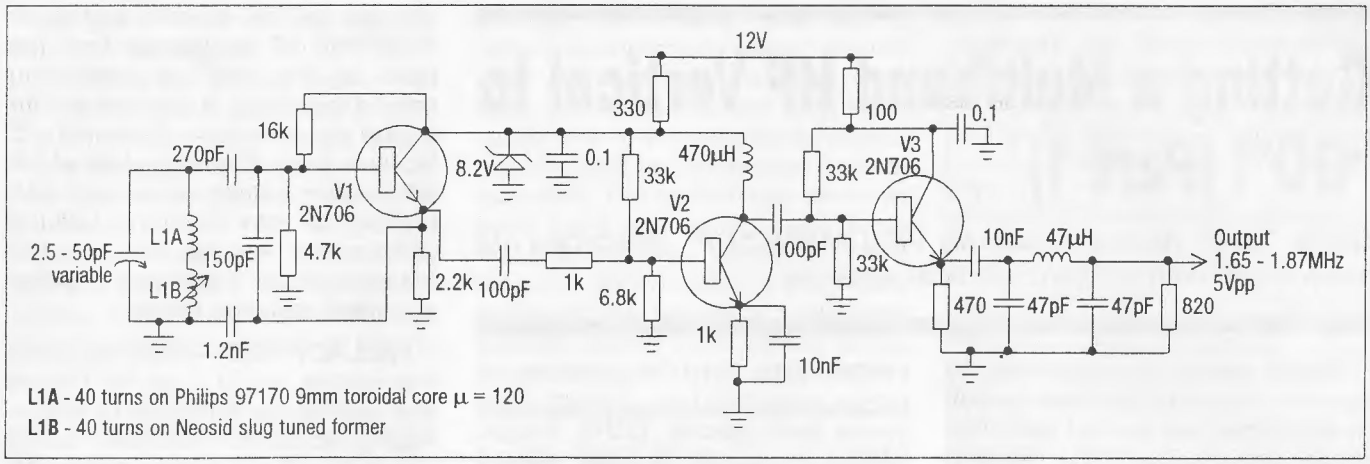

Figure 4 — The VFO is somewhat elaborate and a simpler arrangement is envisaged.

cross-modulation effects can occur if the loop is wrongly peaked to the frequency of a strong local NDB station. A distant signal can also be missed if the signal direction happens to fall within the loop null. In searching for signals, rotation of the loop is part of the tuning ritual.

The multitude of NDB stations above 200 kHz with MCW keyed ident codes provides plenty of test signals for checking out the performance of the converter/receiver rig.

Conclusion

I am satisfied that the converter system works very well for frequencies in the LF range. It incorporates the tuned loop antenna and can limit the bandwidth for narrow bandwidth mode of signals. With the receiver and converter circuits all correctly tuned, I did not notice any undesirable heterodyne beats or cross-modulation effects.

The test rig was made up using a balanced mixer and VFO recovered from a different project. Whilst these worked extremely well to prove the system, some further effort is envisaged to reduce the component count and simplify the whole LF converter. I will pursue the option of using the NE602 balanced mixer later on.

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1. Lloyd Butler VK5BR — VLF-LF and the Loop Aerial — Amateur Radio, August 1990.
2. John Adcock VK3ACA — The day we crossed the Tasman on Long Wave — Amateur Radio, April 1993.

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WIA News

Coast Guard ends Morse Code

The United States Coast Guard has closed down its Morse Code operations on 500 kHz. The final CW transmission ended an era at 0000 UT on 31 July 1993, according to the *W5YI Report.*

Coast Guard operators first began listening for distress signals on 500 kHz at the turn of the century. The Service set up its permanent station almost 70 years ago, to monitor 500 kHz on a continuous basis.

Officials said the advent of satellite communications and digital technology had made Morse obsolete on the high seas.

A misty-eyed Coast Guard radio man tapped out the final 73, saying *"we now look forward to serving you on the next generation of communications equipment and systems via the Global Marine Distress and Safety System (GMDSS)."*

1994 Callbook

The 1994 Callbook was published in October, produced by the WIA Federal Office under direction of Production Editor, Bill Roper VK3BR. Supplies have been despatched to all Divisions, so inquire from them if you wish to order a copy for yourself or copies for your club.

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The Bandwidth Limiting LF Converter Simplified

Lloyd Butler VK5BR continues his development of low frequency receiving converters*

Introduction

In my previous article (ref 1), I discussed reception of signals around 200 kHz and introduced an idea to limit and control the bandwidth of an LF converter. An experimental circuit was presented which made use of discrete component oscillator and mixer modules which I had on hand. I indicated that I would do some further work to simplify the circuit and in particular make use of the NE602 package which is a balanced mixer with inbuilt oscillator facility. The new circuit is now presented.

As in the previous circuit, signal pick-up is via a tuned loop antenna which also provides front end signal selectivity and the mixer output is fed to the receiver via a crystal filter around 1.5 MHz. The reasons for choosing this arrangement were given in the previous article and reference should be made to that article for the background.

The NE602

The NE602 package is a double balanced mixer with an onboard oscillator which injects its signal internally into the mixer. It can operate at frequencies well up into the VHF region and requires minimal peripheral components. To make the oscillator work, it is only a matter of connecting the oscillator section to a crystal or an inductor with associated capacitors in a Colpitts configuration.

The NE602 is finding its way into many amateur radio applications and because of this I think I should highlight a few precautions concerning its application. The first precaution concerns the low input level at which the third order intercept occurs. Let us explain this a little further. The mixer output frequency is the sum or difference of the oscillator and signal frequencies. Other mixing products are also produced, the most significant of these being what are called the third order products. Whilst the output voltage of the desired sum or difference frequency increases linearly with the signal input voltage, the third order products increase in a steeper slope curve following a cubic function law. The curves of figure 1 from the NE602 application notes show how the two components increase with different slopes. It can be seen that there is a theoretical point where the curves cross and the components have equal output voltage. This is called the third order intercept point. Having defined the point, the difference level between the two components, for any signal input level, can be worked out by extrapolating down the linear and cubic law curves from this point.

". . . the input signal range should be between a few microvolts and 27 millivolts."

The level of third order products relative to the desired signal products is a measure of cross modulation in the mixer. To minimise cross modulation, we must ensure that the third order products are well below the desired output signal and for amateur radio purposes, I would suggest a figure of at least 40 dB. To satisfy this requirement our signal into the NE602 mixer should not exceed minus 33 dBm which into its 1500 ohm input resistance is 27 millivolts. (Compare this to the XR2208 package I have previously used as a VLF/LF mixer which can tolerate several volts before third order products become excessive). The consequence of all this is that the level of signal input and pre-amplification (if used) must be carefully controlled to prevent driving the mixer into a state of serious cross modulation.

At the other end of the scale, the minimum level of signal into the mixer is set by its noise floor. The rated noise figure is 5 dB and this works out to around 0.3 microvolts of noise at a 1000 hertz bandwidth across the 1500 ohm input resistance of the mixer. For good signal to noise ratio, the minimum signal level should be somewhat above this figure. Combining this with the previous paragraph, we can deduce that the input signal range should be between a few microvolts and 27 millivolts.

The NE602 can be operated balanced or unbalanced and many of the receiver circuits I have seen in journals have used the unbalanced input form. From my own experience, the mixer performs much better in its balanced form and I don't recommend operating it any other way.

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Another point worth noting is that the NE602 is fully biased internally. If a connection is made to earth or other point with a defined DC level, couple via a capacitor.

The package I obtained was an NE602A which apparently is an upgraded version of the NE602. In examining the application sheets, there doesn't appear to be much difference between the performance of the two. They are both available in different packages and temperature ranges defined by an additional letter code. For example, the N package is the 8 pin plastic DIP in a temperature range of 0 to 70 C.

The Converter Circuit

The complete LF converter circuit including the NE602 mixer (N2) is shown in figure 2. The same loop antenna and loop tuning system is used as in the previous circuit. The high Q loop circuit is tuned to resonance at the incoming frequency. This increases the loop sensitivity and provides selectivity to reduce the level of strong signals at other frequencies. If not attenuated, these could cross modulate the selected frequency in the mixer and hence some form of selective tuning is essential in the front end. If you have any ideas of using a broadband front end with this mixer, then I suggest you forget it.

The high impedance input circuit of the LF353 JFET operational amplifier (N1A) prevents loading and degrading the Q factor of the loop. The LF353 has a satisfactory noise figure and has a gain-bandwidth product of 4 MHz, which makes it suitable for the LF frequency range. If you examine my previous circuit, you will see that the loop interface amplifier had a considerable gain. Not so in the new circuit where the gain is set to 1, limited to prevent excessive signal drive to the mixer. Even with the low signal sensitivity of the loop, the mixer can be easily overdriven. For example, Adelaide Airport Non Directional Beacon (NDB) is around 8 km from my location and this gives a signal output across the tuned loop of 100 millivolts. This level is too high and I have provided a potentiometer RV1 at the output of the loop to reduce level if required. The converter is normally operated with this control set maximum as the loop tuning provides adequate attenuation of strong signals. It is sometimes necessary to adjust the potentiometer down a little when tuning on to the strong station or when tuning to a weak one close in frequency to the strong station.

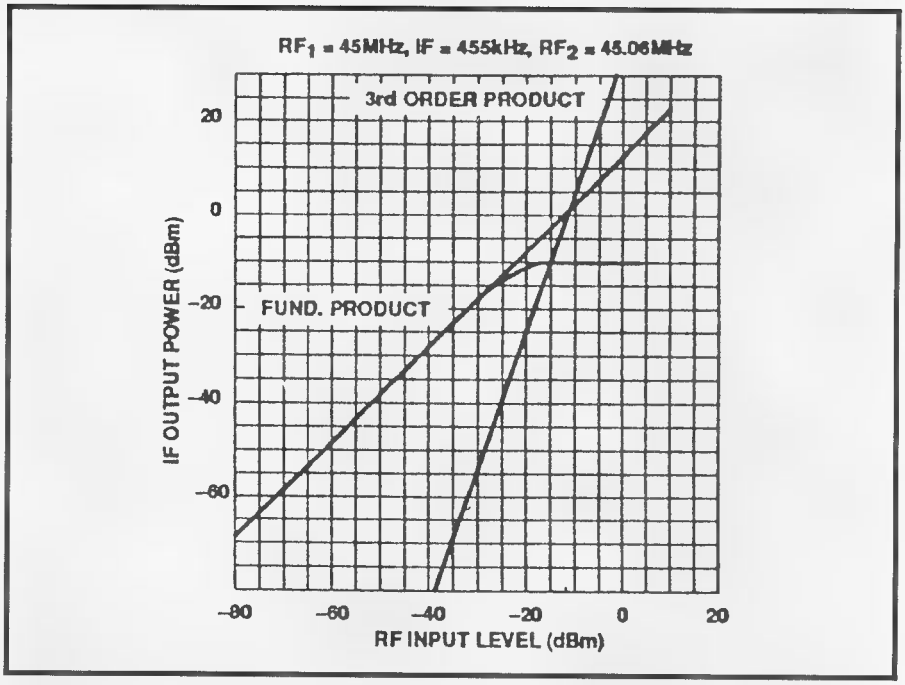


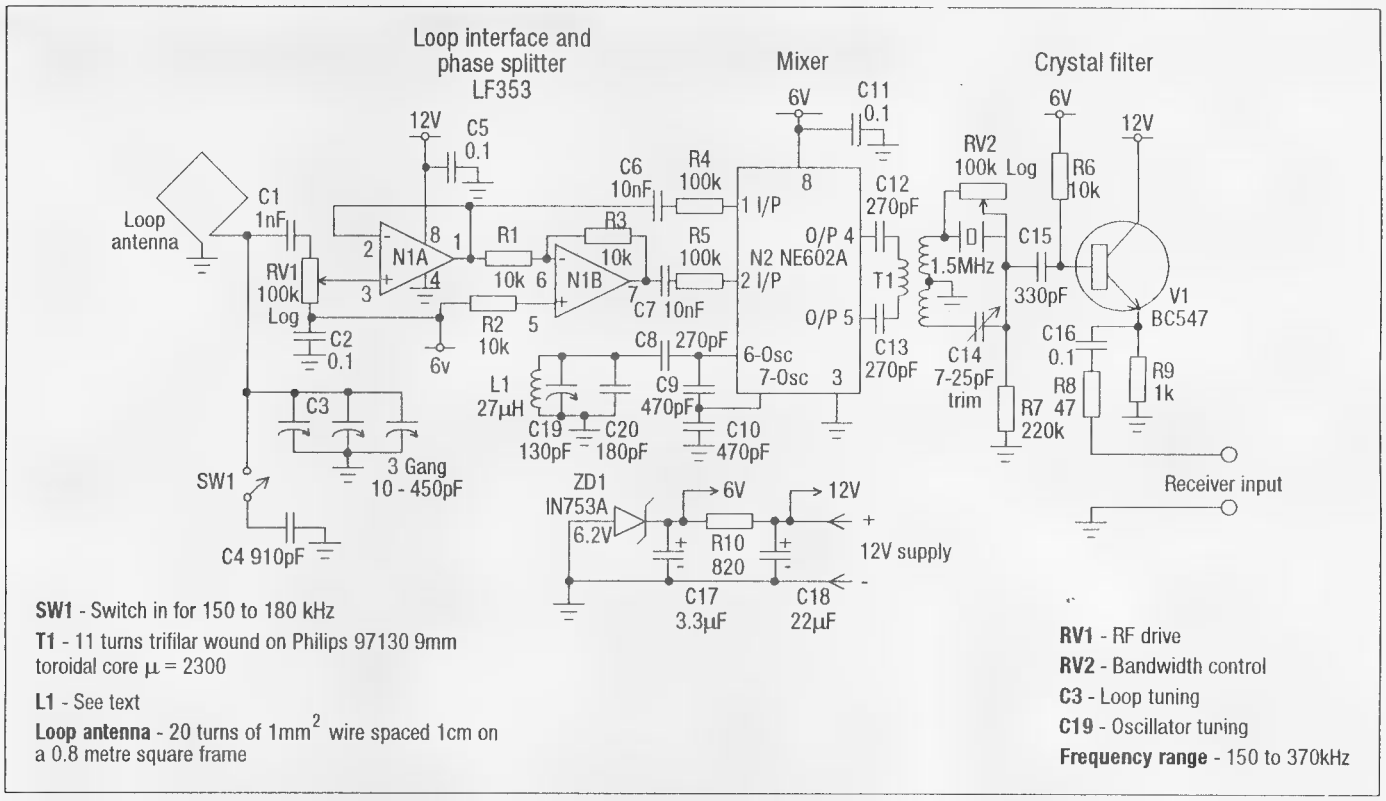
Figure 1 — NE602A — Fundamental and third order products showing third order intercept.

As discussed earlier, the mixer works best in a balanced mode and a transformer can be used at the mixer input to achieve this. Because we are operating down to 150 kHz, we ideally need a primary inductance of 2 mH or more. This is difficult to achieve with the usual toroidal core and is more easily achieved with a small pot core. In my previous circuit, the mixer input was fed via a small toroidal core transformer and I have to confess that there was signal loss due to lack of primary inductance. This loss was made up by extra gain in the drive amplifier. The LF353 has two amplifiers in a single package and in the new circuit I eliminated the need for a transformer by connecting the second amplifier (N1B) as a phase splitter to provide the second half of the balanced input. With the phase splitter provided, the gain from loop output to balanced mixer input is doubled to a value of 2.

No problems were encountered in setting up the oscillator. As in the previous converter, the oscillator is set to tune from 1.65 to 1.87 MHz so that with a first IF frequency of 1.5 MHz, the converter operates from 150 to 370 kHz. Using the Colpitts arrangement shown in figure 2, a 27 microhenry inductor (L1) , a 130 pF variable capacitor (C19) and a number of fixed capacitors achieve the tuning range. The form of inductor is not important but I wound 28 turns of 28 B & S wire on a Philips 97170 toroidal core and juggled the fixed series and shunt capacitors to get the precise range. A 27 microhenry miniature choke also worked OK but I thought the toroid, with its confined magnetic field, might be preferable.

The crystal filter is the same as used in the previous circuit with a 1.5 MHz crystal frequency selected to achieve a minimum bandwidth of around 200 to 250 Hz for narrow band signals. The precise frequency is not important provided the oscillator used in the mixer is adjusted accordingly for the difference frequency. The logarithmic law potentiometer (RV2) across the crystal allows bandwidth adjustment and this was explained more fully in the previous article. The potentiometer must be connected for maximum resistance when set fully clockwise.

The circuit is designed around a 12



SW1 - Switch in for 150 to 180 kHz

T1 - 11 turns trifilar wound on Philips 97130 9mm toroidal core $\mu = 2300$

L1 - See text

Loop antenna - 20 turns of 1mm^2 wire spaced 1cm on a 0.8 metre square frame

RV1 - RF drive

RV2 - Bandwidth control

C3 - Loop tuning

C19 - Oscillator tuning

Frequency range - 150 to 370kHz

Figure 2 — The complete LF converter circuit including the NE602 mixer (N2).

volt power rail although the precise voltage is not too important. The maximum voltage on the NE602 is specified as 8V, hence a lower 6V rail for the mixer has been derived from zener diode ZD1. The 6V rail is also used to set the operating points of the LF353 amplifier and the crystal filter interface emitter follower V1. This saves a few resistors.

Tests on the converter were carried out with the loop antenna indoors and connected through 1.5 metres of RG58 coax. The 0.8 metre square loop is a bit cumbersome inside the radio shack but it works very well in this environment. The only precaution I have had to take is to turn off the fluorescent lights as they radiate quite a bit of RF noise. The loop can be operated outdoors with a longer length of cable but every bit of cable adds capacity across the loop and reduces its maximum tunable frequency. This can be corrected by taking off a turn or so on the loop with a penalty of reduced loop sensitivity.

Assembly

My main aim has been to produce a workable circuit for the converter and at this stage of writing, my test rig is in experimental form with sections of the circuit separately hard wired and fitted together with the tuning capacitors on a base board. So if you are interested in this converter, the layout is now left in your hands. I don't anticipate any layout problems at these low frequencies. A geared drive is essential for the oscillator tuning and desirable, although not essential, for the loop tuning. A shielded lead between the converter output and the receiver is essential to prevent pick up of signals at 1.5 MHz.

Operation

In setting up the receiver, it is first tuned as close as possible to the crystal filter frequency as indicated by the receiver calibration. An NDB signal is tuned in by the converter and the receiver is then finely tuned for maximum signal, preferably indicated on an S meter if fitted. The signal can be located with the crystal filter set for wideband but it is important that final adjustment be made with minimum bandwidth.

Tuning of the loop is fairly sharp and must be set for maximum signal. Manual adjustment of tracking between the loop tuning and the oscillator tuning is simplified if both tuning dials are calibrated for frequency. Some misleading cross modulation effects can occur if the loop is wrongly peaked to a strong signal not selected by the oscillator tuning. In searching for signals, rotation of the loop is part of the tuning ritual.

Performance

Applying a signal generator directly to the LF353 input and using the receiver beat oscillator as for CW reception, the minimum discernible signal level is less than 1 microvolt. For a 30% amplitude modulated signal with the receiver in AM mode, the minimum discernible signal level is 3 microvolts.

The loop Q factor is around 20 to 30, depending on frequency. Using a Q of 20, the calculated loop sensitivity is close to 1 microvolt per microvolt/metre. Minimum discernible field strength is therefore derived as 1 μV/metre for CW and 3 μV/metre for AM. In operation, weak signals just riding above the ambient atmospheric noise have been found to be well

above the minimum discernible level of the loop-converter combination.

Conversion gain from the LF353 input to the crystal filter output is approximately 2 for the widest band setting and 0.5 for the narrowest band setting. Most reasonable receivers can handle signal levels in the order of microvolts and should be comfortable with this conversion gain.

Operated as described so that the mixer is not overdriven, the loop-antenna/converter unit seems free of the odd birdies, often experienced with some superhet receivers which have been extended to tune down to the LF band.

Conclusion

Adding this converter to an existing receiver is a simple way to extend band coverage down to the LF region. Its design was aimed at the reception of experimental signals around 200 kHz such as those recently transmitted from Gordon, Victoria and recent experiments in New Zealand.

The article is an extension of my previous article where I introduced the idea of controlling the received bandwidth within the LF converter. Use of the NE602 mixer has simplified the circuitry. A few notes which I have given concerning the application of this mixer might be of help to others making use of this versatile package. To follow on, I might have look at extending operation down to the VLF range and see how well I can make it work. If it looks OK, a third article in the series might be forthcoming.

References

1. Lloyd Butler VK5BR — A Bandwidth Limiting LF UP Converter for Frequencies around 200 kHz — Amateur Radio, December 1993.
2. Lloyd Butler VK5BR — A Discussion on Mixers — Amateur Radio, April 1988.
3. Signetics Product Specification, NE602 & NE602A.
4. Lloyd Butler VK5BR — VLF-LF and the Loop Aerial — Amateur Radio, August 1990.

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WIA News

Special Event Station

To commemorate the 50th anniversary of the battle of Kwajalein Atoll in the Pacific Republic of the Marshall Islands, special event station V73AX will be on the air, courtesy of the Kwajalein Amateur Radio Club (KARC).

Starting at 1745 UTC on 31 January, the station will operate through to 1920 UTC on 5 February, 1994. Look out for V73AX on the HF bands and six metres (conditions permitting), operating SSB, CW and RTTY.

If you manage to make contact, QSL (with SASE or IRC) to:
KARC
PO Box 444
APO AP 96555 USA
Thanks to John A Taylor V73JT, Vice President of the KARC, for that item.

Region 1 Digital Bandplan Changes

At the International Amateur Radio Union (IARU) Region I Conference late last year, the HF RTTY mode bandplan allocations were renamed "Digimode", to cover all digital transmission modes, including RTTY, AMTOR, PACTOR, Clover and Packet. Some band allocations were increased.

November last's issue of the RSGB's journal *Radio Communications* carried a report on the Conference decisions; the RSGB's *1994 Call Book* carries updated bandplans.

Direction Finder Ducks Back After China Success

Wally Watkins VK4DO, intrepid amateur radio direction finding (ARDF) expert and international traveller, has returned from the wilds of Huairao County in the Peoples' Republic of China, enthusiastic about his Australian team's showing at the IARU Region III contest, held over 5-10 October.

The Federal WIA supported Wally's effort to compete in the ARDF contest in China with a donation of $1000 towards the team's expenses, made earlier in the year.

Other countries taking part in the Region III International Amateur Radio Union's ARDF contest included: Bulgaria, China, North and South Korea, Japan, New Zealand and Taiwan.

Interviewed by the *Sunshine Coast Daily* on his return Wally, a resident of Proserpine Qld, said, "Taking into consideration that the Asian countries have been taking part in amateur radio direction finding for some 30 years, the Australian team performed quite well for its first effort."
Wally and Frank Sleep VK4CAU teamed up to enter the old timers' section of the ARDF contest. Now it must be understood that these direction finding contests are not like the foxhunts we know and love in Australia. They're more a cross between a pedestrian (hah!) foxhunt, orienteering and a cross country foot race. Not for the faint hearted or unfit.

From the start line, you have to charge off — up hill and down dale — to find and record on a card a series of hidden transmitters (all five of them!), before reaching the finishing line. And your time for the hunt/race is recorded — to the nearest second!

Each race is refereed. Before the contest, a training course for international class referees was held in Huairao County and Wally is now Australia's first international referee.

Well done, Wally and team.

Licence Exam Pass Rates Improve

Since the WIA Exam Service started in October 1991, the average per annum pass rate of candidates has climbed from 46.9% in 1991-92, to 57.52% for 1992-93.

Over the period from October 1991 through October 1993, 4063 candidates sat for 7102 subjects. Altogether, 3886 achieved a pass, 54.72% of candidates who sat.

Modifications to the Bandwidth Limiting LF Converter to Include VLF

Lloyd Butler VK5BR further extends the usefulness of his low frequency converter.*

Introduction

In my second article on the bandwidth limiting LF converter (ref 2), I indicated that I would examine the possibility of extending tuning down to the VLF region. Circuit modifications are now described to achieve this and provide continuous tuning between 10 kHz and 420 kHz.

To extend the frequency range downward it has been necessary to expand the frequency range of the local oscillator and provide a means to tune the loop antenna at very low frequencies. I also found a need to modify the loop interface amplifier and the reason for this will be explained further on. No changes were needed in the mixer or crystal filter circuits

The Local Oscillator

The original oscillator tuned between 1.65 and 1.87 MHz for an input signal tuning range of 150 to 370 kHz. To extend the signal range downward to 10 kHz, the oscillator tuning was altered to start from 1.51 MHz. The upper limit was also altered to 1.92 MHz so that the signal tuning range could be extended upward a little further to 420 kHz. This was done because the self resonant frequency of my loop, with its 1.5 metres of cable, was found to be a little higher than the 370 kHz initially assumed. The changes to the oscillator tuning range were easily achieved by replacing the variable tuning capacitor C19 (130 pF) with a 200 pF unit and replacing fixed capacitor C20 (180 pF) with 150 pF.

Loop Tuning

The main complication in extending operation down to the VLF region is tuning the loop at these low frequencies. The loop antenna has an inductance of around 500 microhenries and at the lowest frequency of 10 kHz a capacitance as large as 0.5 microfarads is needed for resonance. Below 100 kHz, the high capacitance required inhibits use of continuous tuning with the variable gang capacitor and we have to resort to switched fixed capacitors. This means that at VLF the loop may be a little off tune for certain frequencies but I have used the switched capacitor idea before and in practice it works reasonably well.

The modified front end of the converter, including loop tuning, is shown in figure 1. Tuning capacitance is controlled by fixed capacitors C22 to C32, switched in by a 12 position rotary switch S1 and a variable 3 gang capacitor C3. For frequencies below 100 kHz, continuous tuning is achieved with C3 in conjunction with the first three switch positions of S1. Below 100 kHz, the variable capacitor has little effect and the switch position is set for a fixed capacitance nearest to resonance as indicated by maximum signal or noise.

One factor I have had to consider is that the loop sensitivity falls as the frequency is decreased. Firstly this occurs because, for a given field strength, induced voltage is directly proportional to frequency. Secondly, the output voltage from the loop is multiplied by the loop Q factor which falls as frequency is lowered. At 300 kHz the loop Q is around 45 but at 10 kHz it falls to around 14. Because of these factors, I found a need to increase the gain of the loop interface amplifier N1A at the lower frequencies. This is achieved by

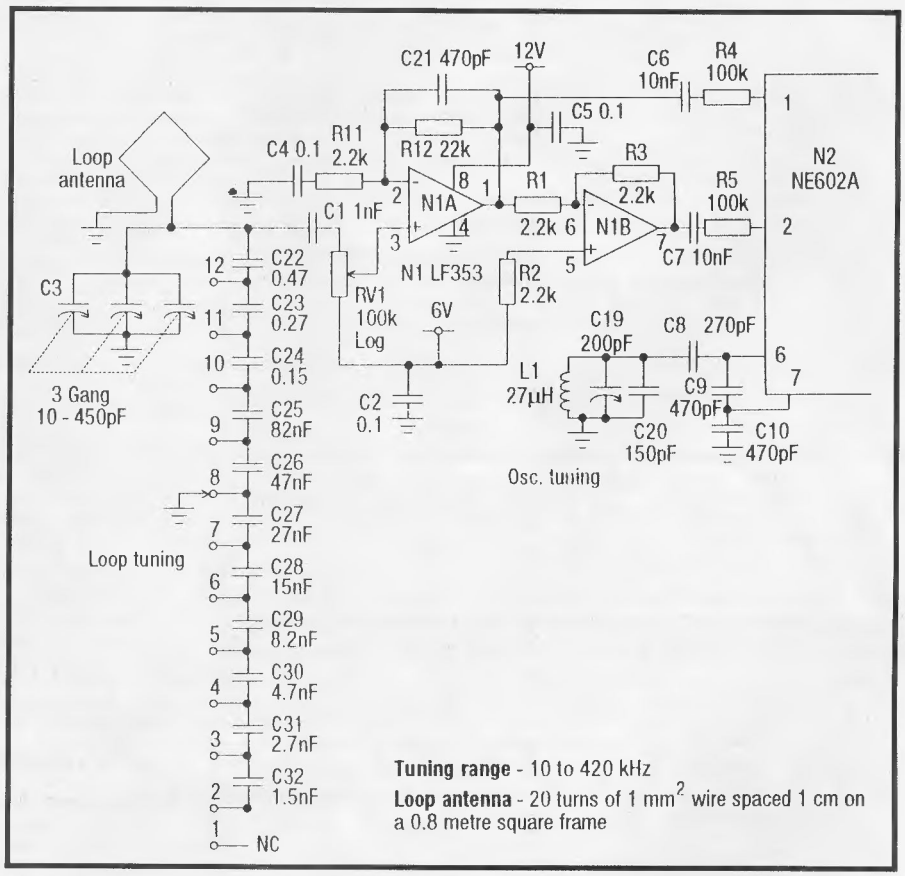

Figure 1 LF converter front end modified for operation to extend to the VLF band.

network R11, R12, C21 connected in the amplifier feedback path. At the upper end of the LF band, the gain of the amplifier is close to unity, but at 10 kHz this increases to nearly 10.

Another modification to the original circuit is a change in the value of resistors R1, R2 & R3 in the phase splitter circuit formed around amplifier N1B. I discovered that this circuit was contributing more than its fair share of inherent noise and to improve the noise performance, these resistors were reduced from their original value of 10 kΩ to 2.2 kΩ. This modification is not specifically related to the VLF modifications as it improves performance at all frequencies.

Whilst I am on the subject of modifications, you might be interested in extending the frequency of the converter in the other direction above 420 kHz. The upper frequency limit is set by the self resonant frequency of the loop connected via its cable. The upper frequency can be extended a little by reducing the capacity of the cable or to a greater extent reducing the loop inductance. This is achieved by switching out a few turns on the loop when operating at high frequencies.

Assembly

All the experimental work was carried in breadboard fashion on the test bench but, having finalised the circuit design, the components were assembled in a small aluminium box.

. . . the gain of the amplifier is close to unity, but at 10 kHz this increases to nearly 10.

The oscillator and loop variable tuning capacitors were each coupled to a dial via an Eddystone 10:1 reduction drive. I happened to have these on hand from some other equipment which was dismantled. For the loop tuning, this gearing is probably an "overkill" but it is essential for finely setting the oscillator when the signal bandwidth is limited to a few hundred hertz. The dials consist of a 6 cm circular metal plate to which paper is glued for marking of the frequency calibration. The oscillator dial is finely calibrated over the whole frequency range of 10 to 420 kHz. The loop dial is calibrated for loop resonant frequency with the loop fixed capacity switch set at its first position. With the switch in this position, the variable loop tuning capacitor covers a range of 200 to 420 kHz. The fixed capacity switch positions are marked with the approximate loop resonant frequency for that setting assuming the variable capacitor is set to minimum. Calibration was carried out with the aid of two signal generators and a frequency counter but in the absence of these, the multitude of NDB stations available and the VLF stations mentioned, provide useful markers. With the calibration in place, tracking of the loop tuning with the oscillator tuning is simplified. Having set loop tuning to near resonance using the calibration, a fine adjustment can be made to peak the signal level.

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BANDPASS FILTERS Narrow band signals like CW require bandpass filters with steep skirts and linear phase response. Linear phase response maximizes the usable signalling rate for a given bandwidth, and minimizes ringing often heard on other types of extremely sharp filters. The filter skirts on the CW filters are so steep that a signal literally falls off the edge of the passband as you tune through a CW signal.

SSB signals often have a high signal-to-noise ratio but have interference from other signals that overlap the desired signal. The steep skirts of the speech bandpass filters allow the interference to be eliminated with minimal impact on the desired signal.

INSTALLATION The DSP-9 is compatible with all amateur radio transceivers and receivers. Just connect the DSP-9 between the radio and its speaker or headphones. Connect 12-16 VDC to the DSP-9 and turn it on!.

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The loop interface amplifier, the mixer and the crystal filter were mounted on separate hard wired cards, the result of three stages of separate experimental development. In duplicating the circuitry, the three circuit elements could be fitted on a single card, perhaps a printed circuit. A 12 position rotary switch was used for the fixed capacitor loop switching. To minimise interwiring, the fixed capacitors were mounted around the contact lugs of the switch.

The front panel controls are the two geared tuning dials, the loop tuning switch and the two potentiometers, one (RV1) to regulate signal level from the loop and the other (RV2) to control bandwidth. The only other external fittings are two BNC connectors at opposite sides of the box, one to connect the loop and the other the receiver input. 12 V DC is picked up from an external supply via a twisted pair.

Operation

For general notes on the operation of the converter, I refer you to my two previous articles (refs 1 & 2). Additional to that, I must emphasise that, in setting the oscillator to receive a given frequency, it is important to first resonate the loop as close as possible to that frequency. If the loop is off resonance, possibly nothing will be heard. Furthermore, if the loop is wrongly resonated to a strong local station frequency, a false condition of cross modulation by that station can occur. With the loop properly tuned, stations such as Omega on 11 to 13 kHz, the North West Cape on 23 kHz, and Belconnen on 43 kHz, feed signals into the attached receiver at S9 level. To detect these signals, the attached receiver BFO is needed. With the BFO on, Omega is heard as changing audio tones as its carrier frequency is switched in slow sequence. The other two signals are frequency shift teletype and also require the BFO. On the other hand, the ident on the NDB stations is modulated CW (MCW) and received in AM mode.

If the local oscillator is tuned down a little further than Omega, a strong carrier will be found. This means that tuning has been taken so far that the local oscillator frequency is close to 1.5 MHz and a signal is fed through the mixer at the 1.5 MHz first IF frequency.

All in all, the VLF converter performs very well over its whole frequency range. At VLF, the loop Q varies between 14 and 25. At these frequencies, frequency separation between stations is very small and my only comment is that a small improvement in the ability of the converter to separate stations at VLF could be achieved if a higher Q front end tuning system was somehow incorporated. Notwithstanding that comment, it pulls in the VLF signals very nicely.

Summary

This concludes my third and final article in the band limiting LF converter series. In my first article I discussed some receiver features which could improve the reception of narrow band mode signals in the LF band including limiting the received bandwidth and use of the loop antenna. I followed on with a description of how some circuitry on hand was used to apply these principles in an LF converter including the use of a crystal filter for limiting the bandwidth. In the second article I refined the circuitry by making use of the NE602 mixer to minimise the component count. The two articles were aimed at providing a converter circuit design for reception of experimental signals around 200 kHz. Having gone that far, I felt compelled to investigate the possibility of extending the tuning range down to the VLF region and the third article introduces circuit modifications which allow operation of the converter right down to 10 kHz.

In concluding, I must emphasise that results achievable with this converter are dependent on loop sensitivity and loop Q. If the loop has a smaller area, lesser turns, or lighter gauge wire (and hence lower Q) than I have specified, the converter will be less sensitive. Furthermore, the loop provides the only front end selectivity and, if the loop Q is lower, there is a reduction in its ability to reject strong out of band signals which might cause cross modulation in the mixer.

References

1. Lloyd Butler VK5BR — A Bandwidth Limiting LF Up Converter for frequencies around 200 kHz — Amateur Radio, December 1993.
2. Lloyd Butler VK5BR — The Bandwidth Limiting Converter Simplified — Amateur Radio, January 1994.
3. Lloyd Butler VK5BR — VLF-LF and the Loop Aerial — Amateur Radio, August 1990.

18 Ottawa Avenue Panorama SA 5041

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WIA News

WICEN in NSW Bushfires

Members of WICEN (NSW) were active in providing support for bushfire fighting operations during the serious bushfires in various regions of NSW in January.

WICEN members were called out on the South Coast, in Sydney South, Sydney North, in the Hunter region, the Central Coast and the Mid-North Coast.

State Emergency Services (SES) communications facilities failed in the Central Coast and WICEN was asked to completely take over communications for them.

Thanks to John Howard, WICEN State Coordinator, for that news.

Packet Radio for Student Training

A packet radio system has been installed by the Royal Melbourne Institute of Technology, Department of Applied Science, to be used as a training tool for students, by staff wishing to access information worldwide, and staff researching the potential of the technology itself.

A Commonwealth grant helped the Department buy antenna equipment, VHF, UHF and 23 cm transceivers, as well as packet equipment required to set up a station for contacting amateur radio satellites, according to a report in RMIT's *"Campus Review"*.

Test Equipment

An LF Antenna Bridge

Lloyd Butler VK5BR
18 Ottawa Avenue
Panorama SA 5041

Foreword

Most of us in VK5 will be well aware that the Coastal Radio Station VIA at McLaren Vale was made redundant a few years ago and purchased by Harro Krause VK5HK as his home QTH. It is a magnificent elevated site for amateur radio, well away from the built up areas and with a large aerial field of masts and transmission lines, the envy of all red-blooded radio amateurs.

As part of the installation, Harro has a beautiful vertical mast 45.72 metres high, insulated at the base and surrounded by 120 earth mat radials each 225 metres long. The original installation also had 90 metre top loading wires to four other surrounding towers. These wires have been removed but, with a bit of work, could be restored. To add to it all, there is a 75 ohm coaxial line and a 600 ohm open wire line already installed back to the radio building.

With or without the top loading, we have the ideal site for some LF transmission experiments and, if we can give him the necessary help, Harro is keen to make the site available for that purpose. Right from the earlier months of 1997, we have been looking at avenues to get an LF licence and how we might set up gear to transmit LF from the site. Initial thoughts were to use the mast as it stands (no top loading, at least for the present).

So that we could correctly couple and load the antenna at its base, we needed to know the values of the resistive and reactive component it presented. Some constants can be calculated but, in the real world, it's nice to be able to measure precisely what one has to work with.

Neither Harro nor myself had gear which could measure the constants required. Some 'farmyard' methods of measurement were tried but results were not too convincing. Also, in making measurements on an antenna at this site, there is a problem of confusing readings caused by RF pick-up from high powered MF broadcast transmitters at nearby Pimpala. The problem of inadequate test gear led me to build the LF bridge which is the subject of this article.

Introduction

The bridge is based on the usual HF noise bridge circuit, which is actually a type of capacitance bridge arranged to measure both positive capacitive reactance and the reverse of this which is interpreted as inductive reactance.

However, it is different from the usual noise bridge in that the bridge components are selected specifically for the LF frequency range and the in-built signal source is a single frequency and not noise.

The single frequency is much more satisfactory to get a bridge balance. As a matter of fact, I often use a fixed frequency with my HF noise bridge for the same reason (*Reference 2*).

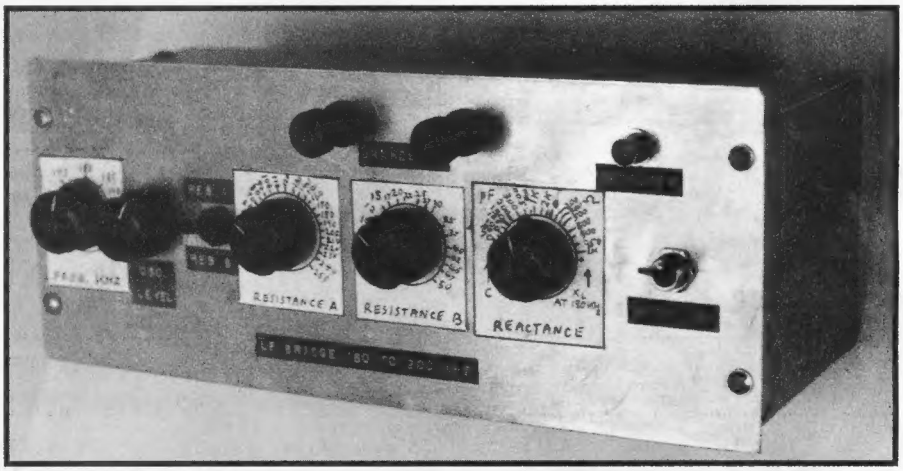
The unit was designed to operate within the range of 160 to 200 kHz, which covers frequencies used by several amateurs operating with Scientific Licences in Australia and the 160 to 190 kHz band allocated to New Zealand amateur stations. At the time of building the unit it was not known that the WIA might make application for an amateur band extending below 160 kHz to include the 135.7 to 137.8 kHz range now available to European amateurs under the CEPT agreement and later to be made available to UK amateurs.

An LF receiver is used as the null detector in conjunction with the LF bridge as is normally done at HF with the HF noise bridge. However, the output to the receiver is fed via a 160 to 200 kHz bandpass filter to protect against cross modulation at the receiver input from the broadcast stations mentioned previously and from VLF noise.

The unit can be used to measure the antenna resistance and reactance constants to assist in the design of the coupling system. It can also be used on the transmitter side of the coupling system so that the system can be checked and adjusted, as necessary, for the desired reflected load. This is done without putting any signal to air from the transmitter and, of course, this is how most people make use of the noise bridge at HF.

Circuit Description

The LF signal is generated by a 555 timer circuit N1 which is adjustable over the frequency range of 160 to 200 kHz. It is inclined to drift a bit when first turned on but it does the job. Its waveform is shaped



Front panel view of the LF Antenna Bridge.

by components L1 and C4, and drive level is set by RV1.

The bridge coupling transformer is fed via balanced driver LF353, N2. The bridge components are the 560 pF capacitor C9 in series with the unknown, 3 x 20 to 460 pF variable gang capacitor C10 with sections paralleled, and either of the potentiometers RV2 (250 ohms), or RV3 (50 ohms).

As with a lot of my projects, the unit was made from gear accumulated in my own junk box but I had some trouble finding suitable potentiometers with low enough inductance for use in RV1 and RV2. Carbon pots are really called for but, in low resistance values, they are a bit hard to find. I didn't have any and I couldn't find any in the catalogues of the local electronics shops.

At these low frequencies a small amount of inductance can be tolerated and several wire-wound pots were checked out for inductance. Most of those measured did not make the grade but I found two which just did the job. The 250 ohm Colvern pot selected measured 7 µH at 250 ohms and 1.4 µH at 50 ohms. This corresponds to a reactance at 200 kHz of 7 ohms and 1.5 ohms respectively. The 50 ohm A G Naunton pot selected had an inductive reactance lower than I could resolve at 200 kHz.

The reason for using the two pots switchable via SW2 was to get a better resolution at values below 50 ohms. Resolution of the larger wire-wound pot at low values is somewhat limited by the spacing between the wire turns and its residual minimum resistance value.

The bandpass filter is made up of a 160 kHz fifth order Chebychev high-pass filter combined with a 200 kHz fifth order Chebychev low-pass filter. They are designed for a circuit impedance of 50 ohms and are terminated in R11, assuming high impedance receiver input.

The unit is powered from a 12 V bank of size AA cells mounted in an eight cell battery holder.

Components

There is one thing about working at these low frequencies. We can select integrated circuit packages which just wouldn't work at HF. Typically, the 555 timer and the LF353 amplifier have been selected.

Potentiometers RV1 and RV4 are carbon types. I would have preferred that RV2 and RV3 also be carbon types but, as discussed previously, low value carbon pots were a bit hard to find.

Inductors L1 to L6 are "off the shelf" miniature RF chokes normally available from electronics stores such as Dick Smith Electronics.

Transformer T1 was made up with 20 trifilar turns wound on a 16 mm ferrite toroidal core recovered from some old gear. The core measured an A_L factor of 1125 mH/1000 T. From this, we deduce that the primary inductance is 450 µH giving a primary reactance of 453 ohms at 160 kHz and adequate for the application (as a rule of thumb, the primary reactance should be at least three times the circuit impedance at the lowest operating frequency).

Of course a maker's type number cannot be quoted for the core but, if anyone is interested, Amidon types FT50A-72, FT50B-43 and FT82-72 have suitable ferrite and A_L factors close to that given above.

The three gang 20 to 460 pF variable capacitor C10 is an old receiver type often picked up at amateur 'buy and sell' marts.

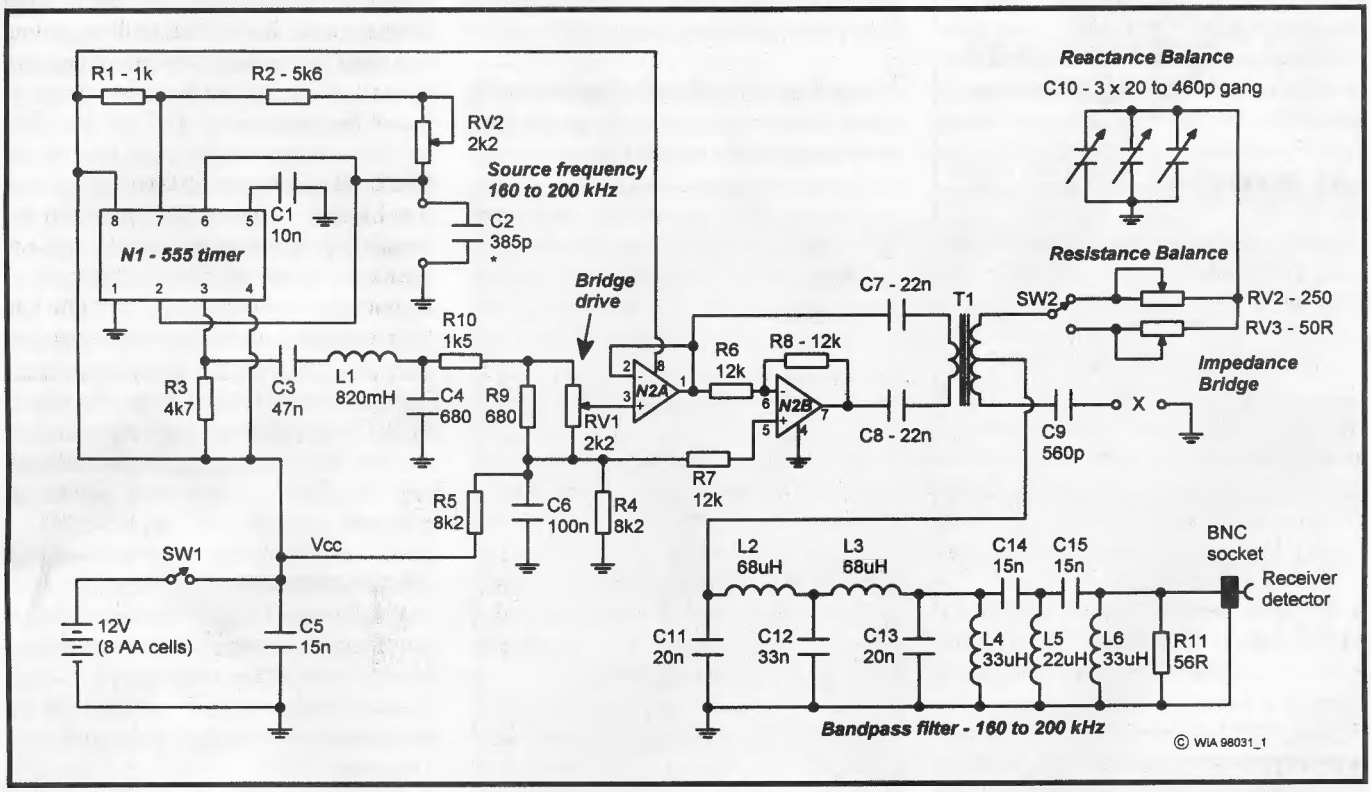
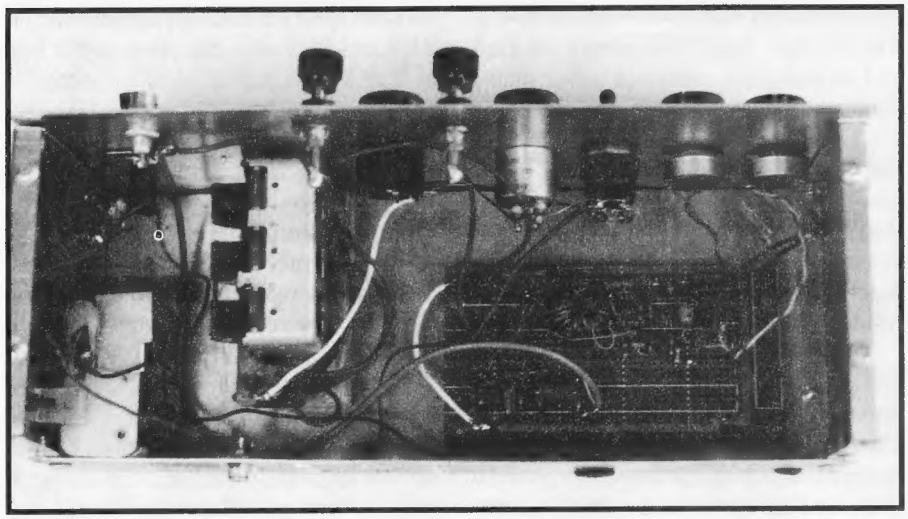


Fig 1 - Schematic diagram for the LF 160 to 200 kHz bridge.
N2 - LF353
T1 - 20 tri-filar turns on a 16 mm ferrite core with an A_L factor of 1125 mH/1000 T.
C2 - Adjust value for frequency range.
L1-L6 Miniature RF chokes (off shelf).



Internal view from the top of the LF Antenna Bridge. The battery pack is at the lower left of the photo, with the three gang reactance balance capacitor to the right of it.

Most of the other components are non critical. Good silver mica capacitors are used for oscillator timing (C2) and in the bridge (C9).

The aluminium case was re-cycled from some other old gear which had been dismantled.

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Calibration and Measurement Range

To be of use, the resistance dials coupled to RV2 and RV3, and the capacitance dial coupled to C10, had to be calibrated against known values of resistance and capacitance.

RV2 is calibrated in a range of 20 to 250 ohms. RV3 is calibrated in a range of 0 to 50 ohms. Positive capacitance of C10 is calibrated in a range of 70 to 3000 pF.

Reverse capacitance is calibrated in terms of inductive reactance at 180 kHz over a range of 0 to 1000 ohms.

Using this type of bridge (as used in the normal HF noise bridge), derivation of capacitive or inductive reactance at a given frequency from the scale as read can be a bit tricky.

For capacitive reactance, simply use the normal reactance formula, $1/2\pi fC$ where C is the capacitance read and f is the frequency.

For inductive reactance, divide the inductive reactance read by the ratio f/ 180 kHz.

As with the noise bridge, there is a calibration where reactance is virtual zero; that is when the capacitance side approaches infinity and the inductive reactance side approaches zero.

As this virtual centre is approached, resolution of precise values becomes cramped; the highest capacitance calibration is marked at 3000 pF and the lowest inductive reactance calibration is marked at 100 ohms.

Summary

I have described an instrument which can be used to measure reactance and resistance components in the LF range of 160 to 200 kHz. Whilst it is not a precision instrument, it can be carefully calibrated to provide useful readings of the antenna constants and be used to assist in adjusting matching to the antenna.

Specification summary:

*Frequency Range - 160 to 200 kHz

*Bridge Resistance Range Calibration - 20 to 250 ohms and 0 to 50 ohms

*Bridge Capacitance Range Calibration - 70 to 3000 pF

*Bridge Inductive Reactance Range Calibration - 100 to 1000 ohms at 180 kHz

*Power Source - 12 V battery (8 AA cells).

At the time of writing, the February 1998 issue of *Amateur Radio* had just been released. In that issue, a press release by the Federal Media Liaison Officer announced the intention by the WIA to revive a submission for an LF band allocation (*Reference 3*).

As the press release indicated an intention to include application for frequencies below 160 kHz, I must now consider the possibility of extending operation of the instrument down to lower frequencies.

The bridge would work OK at the lower frequencies but the oscillator frequency range would have to be expanded downwards and the cut-off frequency of the high-pass filter section would have to be lowered.

As the main function of the complete filter is to remove MF broadcast station interference, it is also probable that it might be satisfactory just to disconnect the 160 kHz high-pass section leaving only the 200 kHz low-pass section in circuit.

References

1. Bob Slutzkin VK3SK - Series of articles on the noise bridge - Amateur Radio, March, April, May 1981.

2. Lloyd Butler VK5BR - Another Tip for Using the Noise Bridge - Amateur Radio, December 1994.

3. WIA News, WIA Revives Submission for LF Band Allocation, Amateur Radio, February 1998.

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Narrow Band Voice Transmission

Lloyd Butler VK5BR
18 Ottawa Ave
Panorama SA 5041

THE MARCH 1995 ISSUE of Amateur Radio included my article "An Adjustable Audio Filter System for the Receiver". This described a system using switched capacitor filters to provide continuous adjustment of lowpass, highpass, narrow bandpass and notch filter characteristics. In the June 1995 issue, I followed up with modifications to allow control of a wide band of frequencies that could be rejected or slotted out within the audio pass band.

Having experimented with the rejection band arrangement, I observed that there was little difference in speech quality if a complete band from 500 Hz to 1500 Hz was taken right out. Only frequencies below 500 Hz and above 1500 Hz seemed important for good intelligibility. I made the point in the article that if noise or interference was concentrated in the 500 to 1500 Hz spectrum, it could be reduced without loss of speech quality by simply slotting out this part of the audio spectrum.

I didn't think much more about this until I read the Pat Hawker Technical Topics column in January 1998 issue of Radcom. He described how in December 1977 issue of QST, Dr R W Harris and J C Gorski announced a new narrow band method of voice communication. The system made use of the characteristic of speech I have just discussed and audio frequencies in the range of 600 to 1500 Hz were not transmitted.

Narrow Band Voice Modulation (NBVM)

Pat Hawker further discusses how the system was perfected by R W Harris WB6CZX and T Lott,VE2AGF/W6. The theory of their system is illustrated in figure 1. Normal speech is transmitted around 300 to 2400 Hz as shown in Figure 1a. In NBVM, freqencies from 600 Hz to 1500 Hz are dropped out as shown in Figure 1b. Frequencies between 1500 and 2400 are then shifted down to occupy the range of 600 to 1500 Hz as shown in Figure 1c. The complete audio band is thus reduced to a range from 300 to 1500 Hz.

In effect the system emphasises the most important information bearing parts of speech (the consonants) but discards the mid range vowel sounds. On reconstruction of the frequency spectrum in reception, the original timbre and voice identification characteristics are retained.

So how is the system made to work? I found some reference in the 1982 issue of the ARRL handbook and this helped me assemble the block diagrams, figures 2 and 3, for the compander system.

Transmission

Figure 2 shows how the speech bandwidth is compressed to feed into the transmitter. The speech is fed via a 2400 Hz low pass filter to restrict upper frequency, out of range, components. A 600 Hz low-pass filter separates the lower frequencies. The whole spectrum to 2400 Hz is fed to a balanced modulator to mix with a 3000 Hz local oscillator. Output components are removed from the modulator below 600 Hz by a low-pass filter. The 1500 to 2400 Hz input components to the modulator are converted at its output to a range of 1500 to 600 Hz but in addition there are a lot of other frequency components generated above 1500 Hz. All the modulator output components above 600 Hz are then summed with the 300 to 600 Hz components at the other leg and fed through a 1500 Hz low pass filter which eliminates the unwanted components above 1500 Hz. Our audio signal is now restricted to 1500 Hz bandwidth to feed the transmitter modulator.

Reception

At the receiving end, the audio output from the receiver is in the compressed bandwidth form and it must be expanded in a reverse process to restore intelligibity. This is illustrated in figure 3. The receiver audio is first fed through a 1500 Hz low pass filter to remove any higher frequency extraneous components. The frequencies below 600 Hz pass through

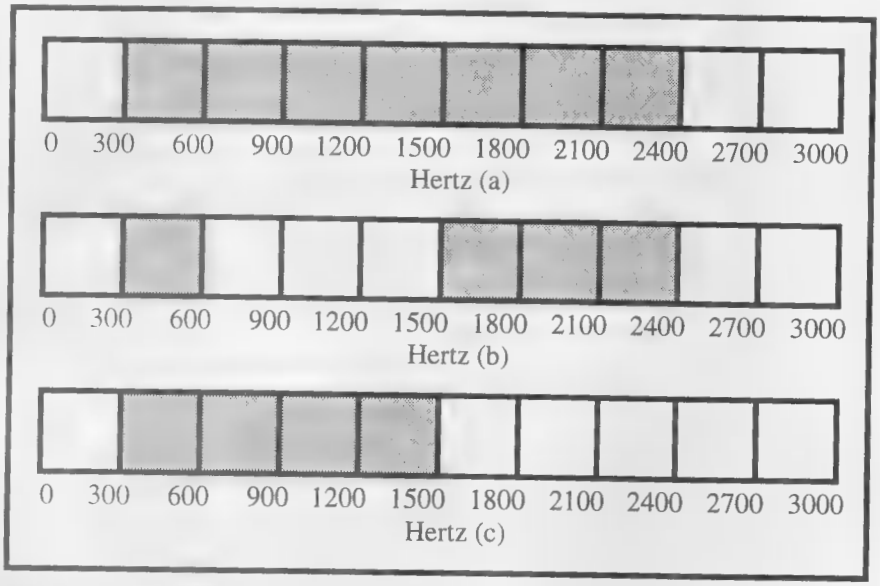

Figure 1. Compression of the voice band for Narrow Band Voice Modulation (NBVM)

(a) Typical normal voice bandwidth used on SSB - 300 to 2400 Hz.
(b) Audio range from 600 Hz to 1500 Hz deleted without loss of intelligibility.
(c) 1500 to 2400 Hz speech spectrum shifted to replace 600 - 1500 Hz content. Total bandwidth is now 1500 Hz.

Source: Pat Hawkins - Technical Topics - Radcom Jan.1998

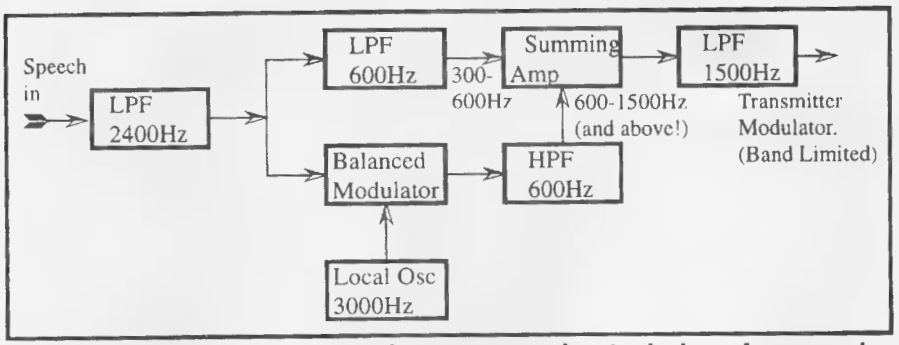

Figure 2. Block diagram showing compression technique for speech transmission.

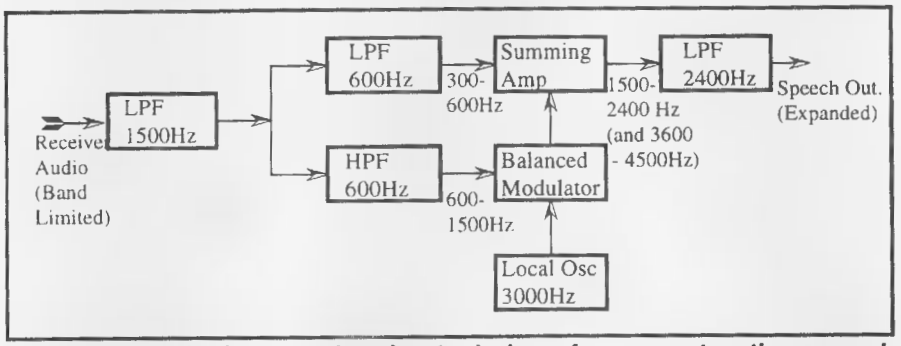

Figure 3. Block diagram showing technique for reconstructing speech on reception.

the low pass filter while those above pass through the high pass filter. The output of the high pass filter, above 600 Hz, are fed to a balanced modulator where they are mixed with a fixed 3000 Hz local oscillator.

The 1500 to 600 Hz voice components are restored at the modulator output to their original frequency spectrum, 1500 to 2400 Hz. In addition there are also other output components above 2400 Hz resulting from the modulation process. The modulator output components are then summed with the 300 to 600 Hz components from the 600 Hz low pass filter. Finally, the combined signal is passed through a 2400 Hz low pass filter to remove the unwanted higher frequencies. We now have the restored signal that can be fed to the receiver loudspeaker.

System Features

So what are the advantages of NBVM? The introduction of single sideband reduced the bandwidth requirement to 50% of the old AM. The NBVM system reduces the bandwidth even further to 62% of SSB. Because of the reduction in bandwidth, we can fit more stations in a given band space and we can expect a nominal improvement in signal to noise ratio of around 2 dB.

The Technical Topics report indicates quite high speech quality with only the 1500 Hz transmission bandwidth. In fact the report further indicates that if intelligibility only is required, a bandwidth of 1200 Hz or even 1000 Hz is possible by using a rejection band of greater than the 600 to 1500 Hz discussed. My own tests using the tunable filters confirmed the good speech quality for a band rejection extending up to 1500 Hz but the tests also demonstrated the loss of quality as the rejection band was extended upward above 1500 Hz.

But what are the negatives? There is the complication of providing four fixed audio filters to transmit and four to receive. On the other hand, the filtering is all done at audio level and need not involve internal modification to transmitter or receiver. Of course in this day and age of modern digital technology, the whole filtering process could be easily achieved using digital signal processing techniques and indeed it might already have been incorporated in some of the modern digital signal processing gear.

Another factor is that if you decided to transmit with this system, you could only communicate with someone who had installed the corresponding audio receiving gear. Pat Hawker writes about the lack in popularity of NBVM in amateur radio circles. He said "These disadvantages have evidently been judged to outweigh the greater spectrum efficiency and fairly modest improvement in SNR."

As I said earlier, the principle of dropping out the speech components in the frequency range of around 500/600 Hz to 1500 Hz in the NBVM system tied in nicely with what I had found experimenting with my adjustable filter unit. I thought it would be an interesting subject to reintroduce to the columns of our AR journal.

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References

1. Lloyd Butler VK5BR - *An Adjustable Audio Filter System for the Receiver* - Amateur Radio, March 1995.
2. Lloyd Butler VK5BR - *The VK5BR Audio Filter, Modifications to include an Adjustable Rejection Band.*
3. Pat Hawker G3VA - *Technical Topics* - Radcom, January 1998
4. *ARRL Handbook*, 1982 edition - Chapter 14, Specialised Communications Systems - Page 14-33

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An Experimental Low Frequency Band Transmitter

Lloyd Butler VK5BR

Early in 1997, with the help of Harry Krause (VK5HK) I took some steps to experiment with test transmission in the Low Frequency (LF) region of the radio frequency spectrum. The plan was to transmit from the QTH of VK5HK which is the old coastal radio site (previously VIA). The site has an ideal vertical antenna tower for the purpose and Harry was happy for this to be used for the tests in conjunction with other facilities he has on site. I discussed the previously in my article on the LF bridge (*Amateur Radio* October 1998 – reference 1).

AMATEUR LF BANDS have been approved and are already in use in various countries around the world such as the United Kingdom, New Zealand and countries in Europe. ARRL have applied for approval in the USA and the WIA have made approaches to the authorities in Australia. In the absence of an amateur licence approval we did consider a scientific licence as granted to several other experimenters in Victoria and Tasmania, but the licence fee has been increased and operating conditions looked a bit restrictive.

All in all, I guess we just let the project ride, hoping that WIA would succeed in their bid to get an LF band allocation. However, I did build a transmitter ready to send out the test signals. So far it has done no more damage than heat up my dummy load but I thought it was high time its design was committed to the documentation which follows.

The transmitter has been designed to operate within the frequency range of 160 to 200 kHz, essentially to correspond with out nearest LF active country New Zealand which has a band approval of 160 to 190 kHz. (If Australia gets approval outside the range, say 135-138 kHz as in the UK, then I guess the transmitter range will have to be modified).

The transmitter power amplifier can deliver 70 Watts of RF power via a 25 Ohm 220 khz LP filter into a 25 Ohm resistive load (The power output could be increased to 100 Watts if the output circuit were changed to suit an 18 Ohm load).

It was proposed to operate the transmitter to air in a keyed continuous wave (or CW) mode from an auto-keyed pre-programmed Morse ident signal. Provision has been made to key from either audio tone or direct DC control. The RF power amplifier operated in a linear mode and hence the transmitter circuit could also be arranged to accept a speech modulated RF signal such as AM or SSB instead of the continuous RF signal now taken from a VFO.

The transmitter was constructed almost completely from components I had available around the radio shack. (I think the only component I had need to buy from the electronics store was a thermistor). Because of this you may see examples of where the component count is higher than it need be, such as using three transformers to get 50VAC when one would have done. My philosophy – why spend $50 (or more) when I can find a way to do the job for nothing out of the component junk-box.

Photo 1: LF Transmitter — RF Unit and VFO

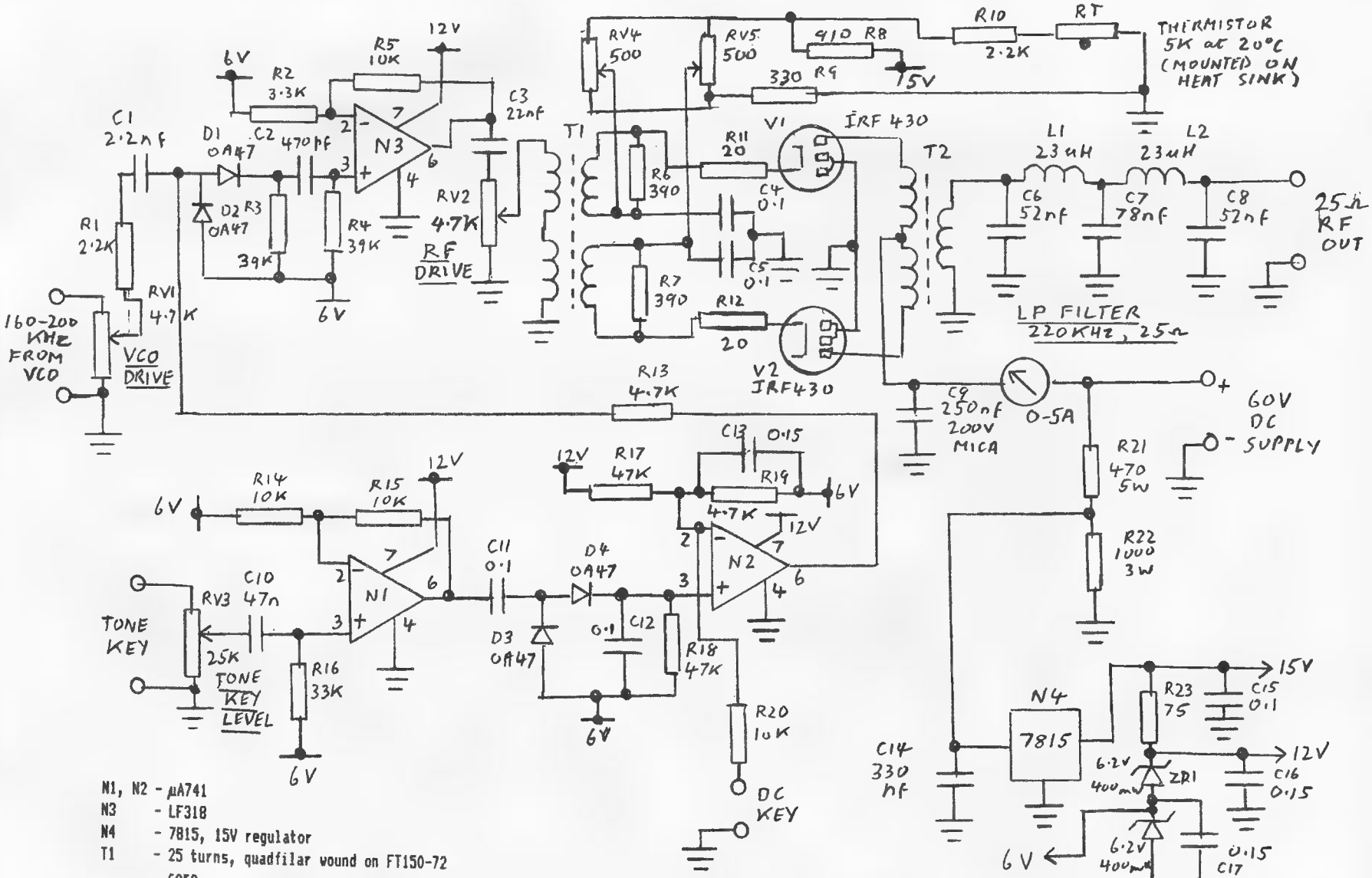
The RF Circuit

The circuit of the RF Power Amplifier, RF Driver and keyer system is shown in figure 1.

The RF Power Amplifier uses a pair of HEXFET IRF430 transistors (V1,V2) operating in a linear mode, push-pull class B. The design of the circuit is based on one which I had previously submitted and which was published in Amateur Radio, November 1989 (ref 2). For more detail on the characteristics of the HEXFET transistors and the circuit design, I refer you to that article.

Using the output transformer as shown, the amplifier can deliver 70 Watts into 20 Ohms (or 100 Watts into 18 Ohms) with an efficiency around 60%. (The remaining 40% is of course heating of the transistors). The transistors are mounted on 6 inches

continued on page 25



N1, N2 - µA741
N3 - LF318
N4 - 7815, 15V regulator
T1 - 25 turns, quadfilar wound on FT150-72 core
T2 - 22 turns trifilar wound on 620-55254 iron dust core (4aa, Al = 175mH/1000T)
L1, L2 - 26 turns on FC334 T130-3 core

FIGURE 1

LF TRANSMITTER

KEYER CIRCUIT, RF DRIVER & POWER AMPLIFIER CIRCUITS

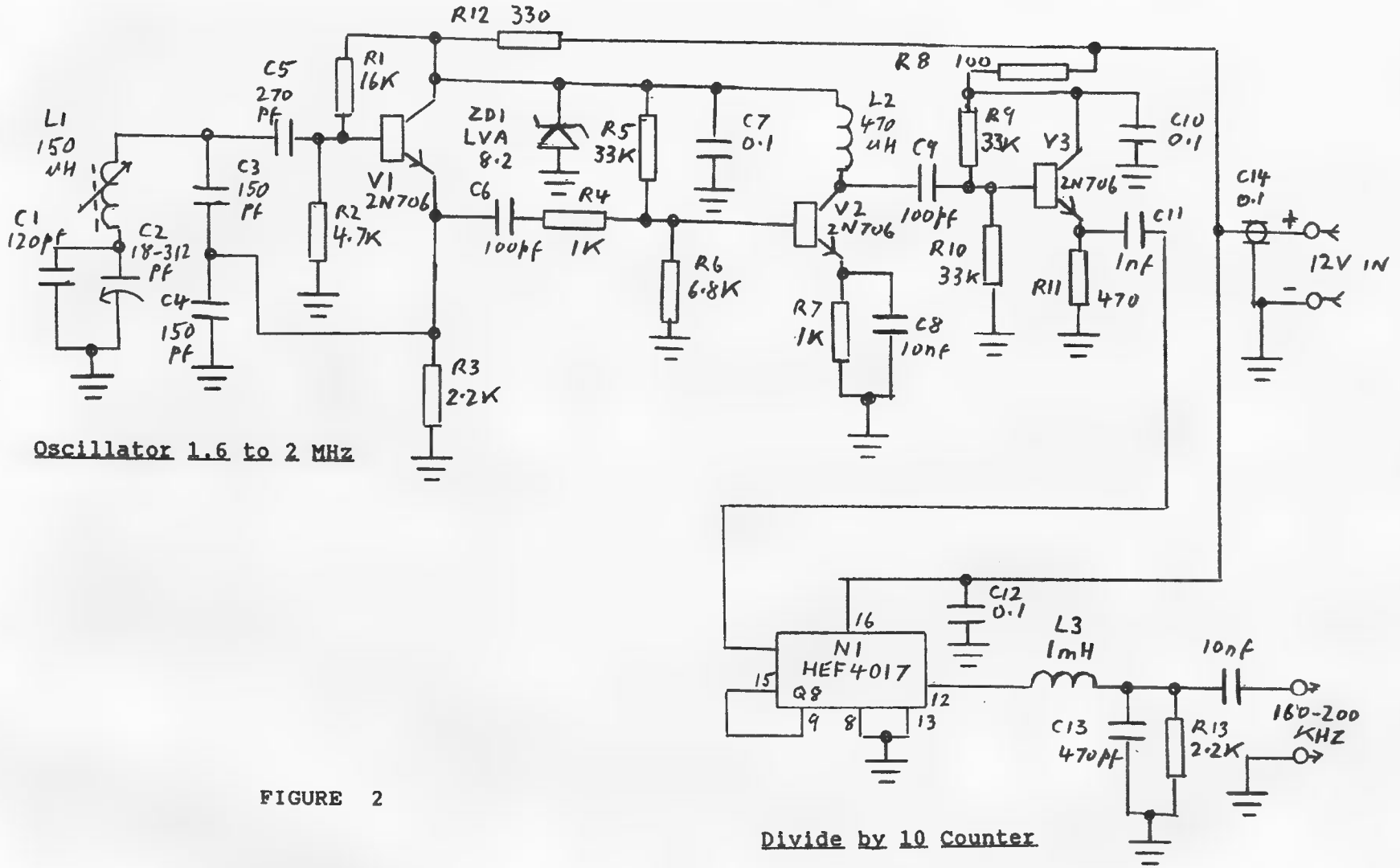


FIGURE 2

LF TRANSMITTER

160 - 200 kHz VARIABLE FREQUENCY OSCILLATOR (VFO)

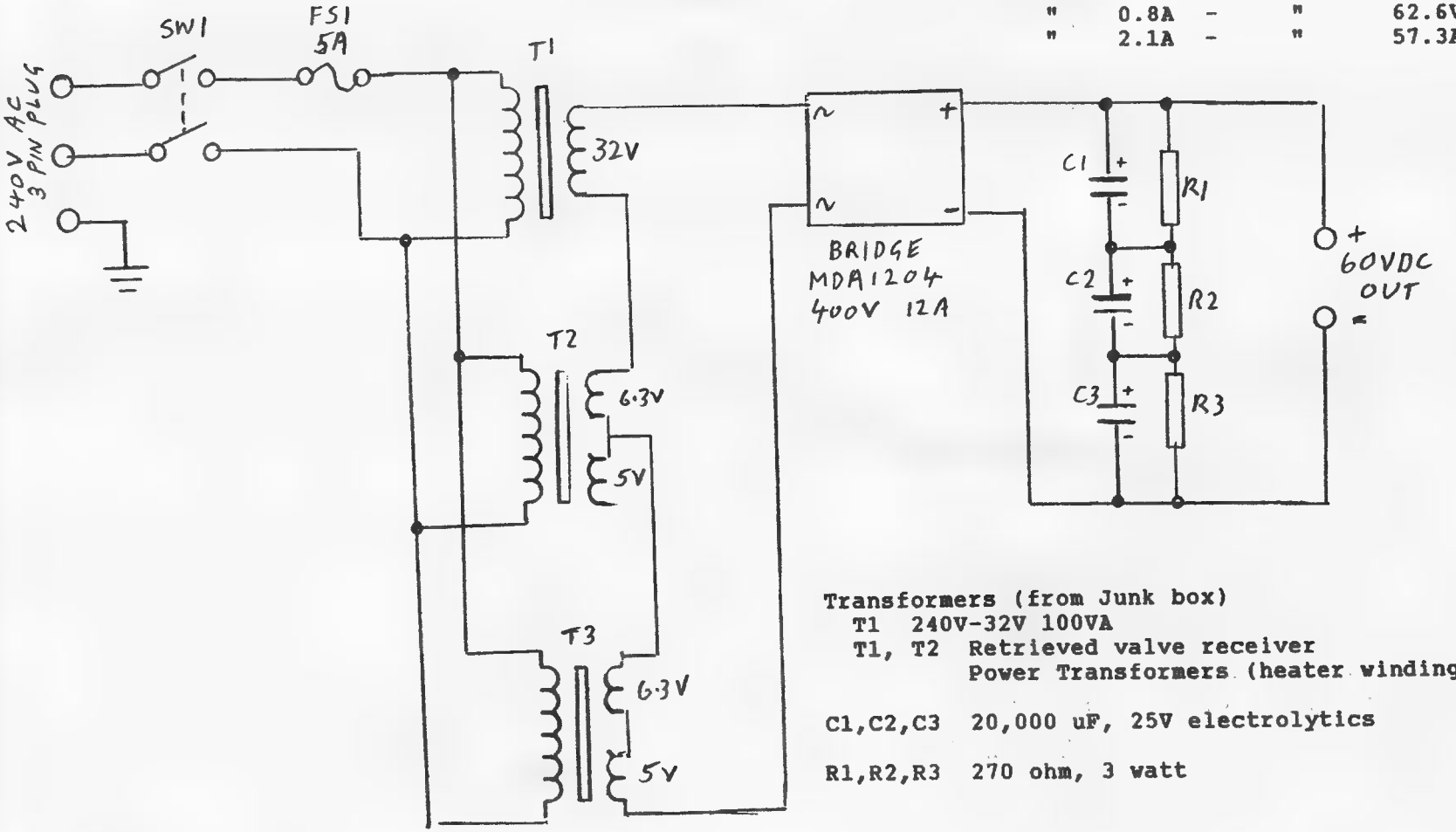
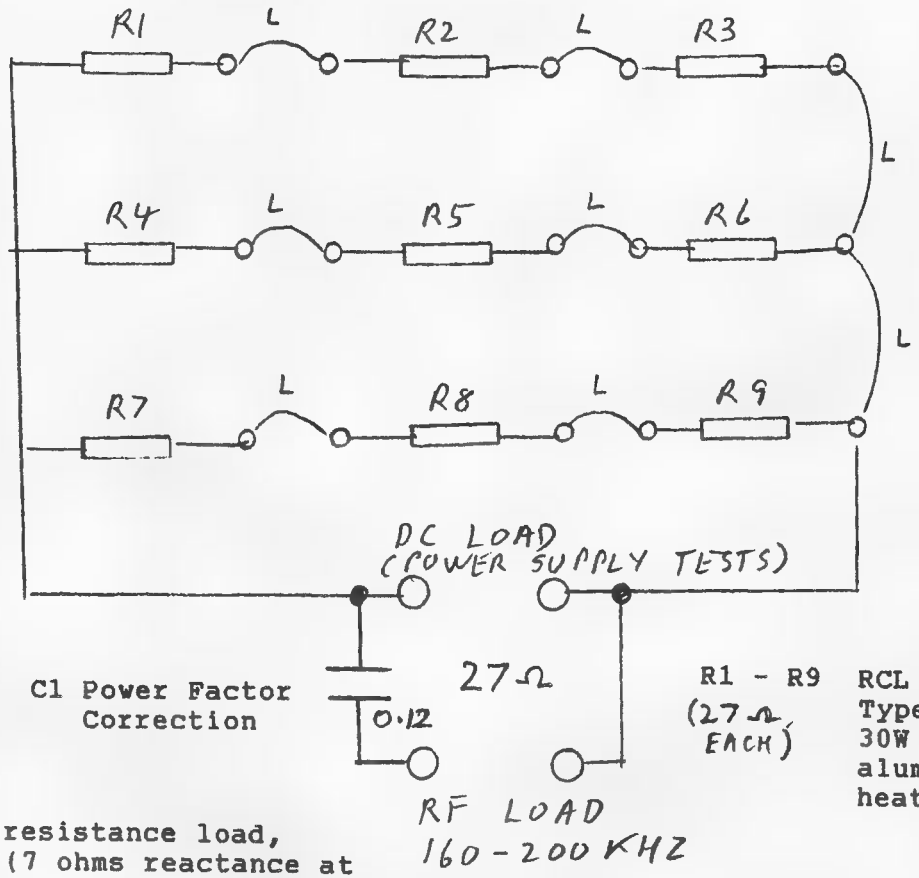


FIGURE 3 LF TRANSMITTER

60 VOLT 3 AMP POWER SUPPLY



L = Links to alter load if required

R1 - R9 (27Ω EACH) RCL Aluminium Housed Beryllium Type ALB50 Rating 50W at 25C & 30W at 125C (Mounted on 3mm thick aluminium sheet 400mm x 230mm as heat sink)

Connected as 27 ohm resistance load, inductance is 6µH. (7 ohms reactance at 180kHz - corrected by 0.12µF capacitor)

FIGURE 4

LF TRANSMITTER

DUMMY POWER LOAD RESISTANCE (DC & RF)

continued from page 20

(150mm) of Minifin heatsink via beryllium insulating washers. With natural convection, the thermal resistance of the Minifin is around 1 degree Celsius per Watt and the washers 0.1 degrees Celsius per Watt. As such, the temperature rise at the transistor case could be around 56 degrees for an anticipated heat dissipation of up to 40 Watts (continuous signal). This should hold the transistors within their temperature tolerance, but just to make sure, I bolted some extra aluminium fin material to the two sides of the Minifin. In practice operating at 70 Watts of continuous output, the transistors run at quite a moderate temperature as felt by the hand. (Of course, in keyer operation the average output power and heat dissipation is even much less).

Static drain current (no signal) is set to 150 mA per transistor (300 mA total) with trim pots RV4 and RV5 which control the forward bias voltage). Thermistor Rt is mounted in direct thermal contact with the heat sink and connected in the gate bias circuit. This reduces bias as the temperature rises to hold static drain current reasonably constant with temperature rise the need for this was explained in Reference 2. As full power of 70 Watts loaded into 25 Ohms, total drain current rises to around 2 Amperes.

The RF output is fed via a 5th order Chebychev 220 kHz low pass filter designed for the 25 Ohm load. Theoretical attenuation at the first octave in this type of filter is in the order of 55 dB and harmonic radiation could be expected to be more than 70 dB below carrier level.

The nominal drain supply for the output transistors is 60 volts DC. This is dropped down to 15V via regulator N4 for the gate bias supply. The 15V in further reduced, using zener diodes ZD1 and ZD2, to provide 12V and 6V supply liner for the RF driver and keyer stages: N3, N1 and N2. The 12V is also fed out to the VFO which is built in a separate shielded box to that containing the transmitter, driver and keying circuits.

Carrier on/off for keying in controller by the gates D1 and D2. For gate closed, D1 is reverse biased and D2 conducts to loop the RF line from the VFO. For gate open, D2 is reverse biased and open and D1 conducts to connect the VFO to the input of stage N3. Stage N2 provides the switching voltage in turn controller either by opening on closing the DC key line of keyer tone. The DC keying is applied via the inverting input of N2. Keyed tone is fed via stage N1 to rectifier circuit D3 and D4 which develops a DC voltage to control N2 output via its non inverting input.

Photo 2: LF Transmitter
Rexfet Power Transistors mounted on heat sink

The Variable Frequency Oscillator (VFO)

The VFO provides output tunable between the range of 160 to 200 kHz. The circuit diagram is shown in figure 2. The tunable oscillator V1 operates at 10 times the base band frequency (ie 1.6 to 2 MHz) rather than at the base band frequency itself of 160 to 200 kHz. The 10 times arrangement is done for two reasons:-

(1) It is more convenient to provide a small tuning capacitor to cover the range of 1.6 to 2 MHz than is the larger variable capacitor needed to tune the LF band.

(2) By operating the VFO at a remotely different frequency, there is less chance of any instability problem due to feedback from the high power output of the transmitter into the VFO.

The card containing the variable oscillator V1 and buffer stages (V2 &V3) was already assembled as I had used that card for several projects before. I simply had to adjust the tuning range, calibrate the dial and add the divide by 10 stage N1. Frequency selection is controlled by variable capacitor C2 which is coupled to a vernier drive dial.

The output of N2 is a square wave and this is shaped to sine wave form by filter L2-C13. Output voltage from the filter approached 15Vpp. This is too high for the input of the keying gate and RF driver and its level is reduced by potentiometer RV1 (Fig 1)

60V Power Supply

The circuit of the 60 Volt power supply is shown in figure 3. This is a simple unregulated supply using a transformed secondary voltage of about 50. The output is rectified by a bridge package and filtered by a large parallel capacitor.

I didn't have quite the right transformer, so I used a heavy duty 30 volt transformer which I did have and built up the voltage to 50 by series connection of the heater filament supply secondaries of two retrieved valve power supply transformers.

Another item I did not have was a very large capacitor with a voltage rating exceeding the peak DC output voltage. I did have some 20,000 µF electrolytic capacitors rated at 25V so I connected three of these in series to provide 6700 µF at 75V. The three power transformers and three large capacitors made up a lot of bulk and weight and the whole supply was mounted on a discarded valve receiver chassis which had been stripped of previous components.

With this simple type of power supply, there is quite a bit of voltage swing between the key up and key down states. For the proposed CW operation this is of little concern. On the other hand, if the transmitter were to be used in an SSB mode, some compression of the modulated signal

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could be expected at the signal envelope increases in amplitude with speech lever upward swing. For this mode, improved regulation in the power supply might be desirable.

The Dummy Load

Having selected 20 Ohms as the operational load, a dummy load close to 20 Ohms was needed for test purposes. Fortunately, at LF it is possible to use some types of power resistor which would otherwise would be unsuitable for higher frequencies because of their inductance and distributed capacity. I made up a load using nine 27 Ohm aluminium housed beryllium resistors in a series/parallel connection and mounted them on an aluminium sheet, 420mm by 230mm by 3mm thick, for a heat sink. The arrangement, shown in figure 4, can dissipate 300 to 400 Watts depending on resistor case temperature. With 70 Watts of power from the transmitter, there is barely a temperature rise.

Load resistance values other than 27 Ohms are arranged by altering connection links between the individual resistors. The inductance in series with 27 Ohms resistance is close to 6µH which represents only 7 Ohms reactance at 180 kHz. This reactance is essentially cancelled by the power factor correcting capacitor of 0.12µF in series.

Apart from its function as a RF test load, the dummy load (without series capacitor) was also put to use to carry out DC load tests on the power supply.

Transmission Line and Antenna Matching

As these low frequencies, unless one has a large canyon to hand and antenna, the effective antenna length is very much smaller than a quarter wavelength. Hence, radiation resistance is very low (often somewhat less than an Ohm) and the antenna must be loaded with quite a large inductor which inherently has loss resistance quite high compared to the value of radiation resistance. Added to this is the installation earth loss resistance. All in all, unless the antenna is of massive proportions, most of the power delivered is consumed as loss in the inductor and loss in the earth system.

My initial thoughts were that we would be unlikely to get a total Load resistance (radiation plus loss) below 25 Ohms. That is the reason I selected 25 Ohms for the load circuit of the transmitter, expecting to feed the antenna directly from the transmitter.

Further to that, Harry was able to provide a big inductor coil which could be adjusted up to 1.2 mH and had a Q of around 300. I figured from measurements and some calculation that, at mid band frequency (180 kHz), his vertical tower would have a radiation resistance of around 0.5 Ohm and a capacitance of around 850pF. I decided that, loaded with his inductor, we would have a loss resistance in the inductor of 3.5 Ohms and I made a guess that his extensive earth system would have a loss resistance within one Ohm. Hence, out total load would look like a resistance of 5 Ohms and radiation efficiency would be 10% (For 70 watts of transmitter power we would radiate 7 watts).

Rather than operate the transmitter right at the antenna, it was decided that it would be more convenient to locate the transmitted in Harry's radio shack (the old VIA control room) and feed the antenna via a 225 metre length of 75 Ohm coax already in place to the antenna. (At these frequencies, power loss in the coax would be small). A proposal for the system is shown in figure 5. The transmitter would be coupled to the coax via a 25/75 Ohm transformer mounted at the transmitter. An L match at the antenna would match the coax to the antenna low resistance circuit. A shunt capacitor of around 43 nano Farad would be needed and the 1.2 mH coil would be adjusted to provide the series reactance for the L match plus the inductive reactance to load the antenna (ie. to cancel its capacitive reactive component).

Well, the operational installation has never been put into practice but we did formulate the plan. Also considered was the possibility of transmitting from my home. However, with the limited antenna I could provide, radiation resistance would be a mere fraction of an Ohm and radiated power would be but a fraction of a Watt.

RF Capacitors

One problem I encountered with this project was finding suitable capacitors to operate at high power in the RF transmission circuit. At these low frequencies, capacitance values are quite high and not only do they have to withstand the peak RF voltage, they also have to pass quite high reactive current. As I explained in a previous article (*Amateur Radio* January 1995, ref 3), RF current through loss resistance in the capacitor causes heating (ie. power lost) and if heating is excessive it can damage the capacitor.

For the three LP filter capacitors C6, C7 & C8 in figure 1, the best I could do was to make up the required values with 600V polyester tubular capacitors. At nominal values of 52 and 78, nano Farads, peak current for 70 Watts output is in the order of 4 to 4 Amperes. These capacitors were hardly designed to stand this sort of treatment and it is not surprising that, in a sustained carrier condition, they run warm. It is a worry that they might not withstand prolonged operation and I would like to replace them with more suitable mica or high power disc ceramics.

Another problem capacitor is the 42 nano Farad one proposed as part of the L matching network (figure 5). A suitable type of capacitor with high current rating would also have been needed for this application.

A third capacitor to mention is bypass capacitor C9 as the centre of T2 in figure 1. This point is virtually RF cold but the capacitor does have to conduct any out of balance current between V1 & V2. For this job, I had a nice 250 nano Farad 200V mica available.

Summary

Described is an LF transmitter assembled essentially from components accumulated in the amateur radio shack. Also described are details of a plan we had to use the transmitter to send out test signals from the old Coastal Radio Site VIA (Now the home and amateur radio station of Harry VK5HK).

In its present form, the transmitter can operate within the range of 160 to 200 kHz at a power of 70 Watts keyed in a CW mode) At the time of writing, we wait the success of the WIA in seeking a LF band segment for licensed amateurs. If they do succeed and the approved band is outside this transmitter frequency range (say 138 kHz as in UK rather than 160-190 as in NZ) then I will have to change the VFO frequency range and the cut-off frequency of the LP filter at the output.

I guess every frequency band offers its own design problems. As LF it is not lead length or stray capacitance but more about larger inductors and finding suitable capacitors. Above all it is about how to radiate some useful power from an antenna limited in size compared to a wavelength. Also to get on the air below 200 kHz, it is a case of either build a special transmitter or modify one made for higher frequencies. So it's home-brew just like the good old days!

References

1 Lloyd Butler VK5BR – A LF Antenna Bridge – *Amateur Radio*, October 1998

2 Lloyd Butler VK5BR – RF Power Linear Amplification using the IRF MOSFET – *Amateur Radio* November 1989

3 Lloyd Butler VK5BR – Capacitors at High RF Power *Amateur Radio* January 1995

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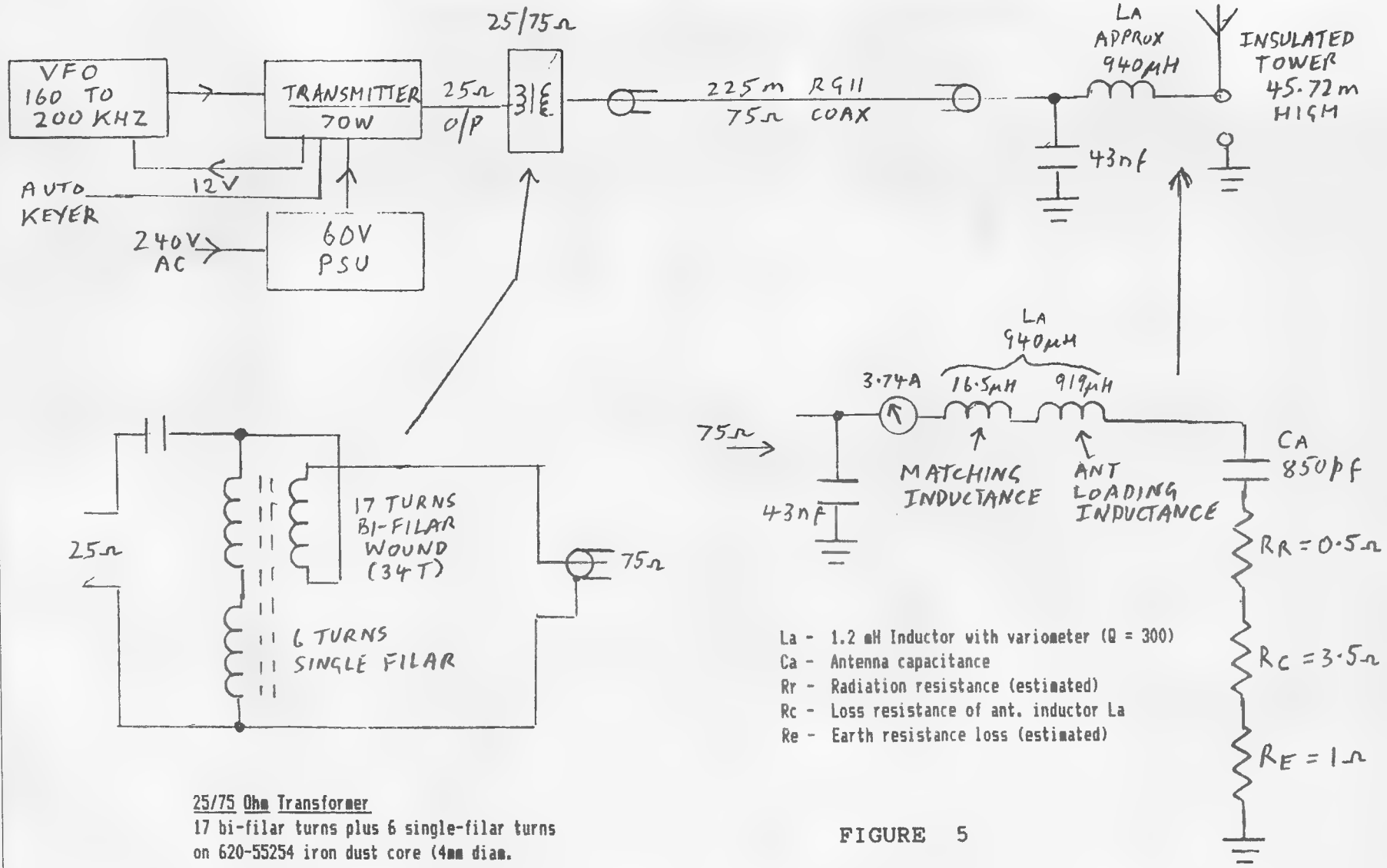

La - 1.2 mH Inductor with variometer (Q = 300)
Ca - Antenna capacitance
Rr - Radiation resistance (estimated)
Rc - Loss resistance of ant. inductor La
Re - Earth resistance loss (estimated)

25/75 Ohm Transformer
17 bi-filar turns plus 6 single-filar turns
on 620-55254 iron dust core (4mm diam.
Al = 175mH/1000T)

FIGURE 5

LF TRANSMITTER

PROPOSED ARRANGEMENT TO FEED & LOAD VERTICAL ANTENNA TOWER

LF Receiving Converter with Loop-stick Antenna

Drew Diamond, VK3XU
45 Gatters Rd.,
Wonga Park, 3115.

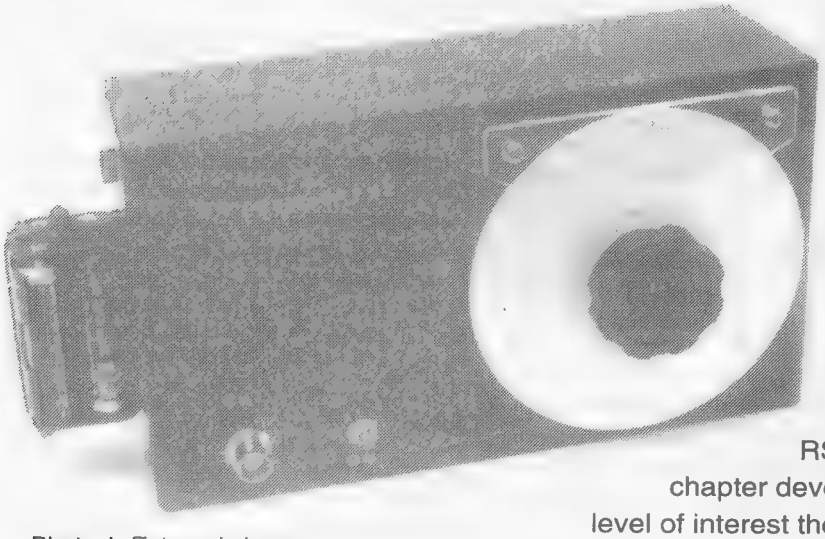

Photo 1: External view

Interest in LF techniques appears to be gaining momentum. Specially licensed experimenters have been transmitting LF test signals in our region, and Amateurs in some European countries have had access to an LF allocation for a few years now. Indeed, the latest RSGB Handbook now has a substantial chapter devoted to LF, which perhaps indicates the level of interest there.

As with any radio work, it is necessary to gain some preliminary understanding of propagation by listening for stations on that band. Signals from amateur/experimental transmitters are generally much weaker than the navigation beacons there. In addition, electrical noise, even in a leafy residential suburb can be very high. Unfortunately, LF band performance on some general coverage receivers may prove inadequate for serious listening. A simple wire antenna will bring in many of the beacons, along with a galaxy of noise spurs from electrical appliances in the neighbourhood. Unless the receiver has a very remarkable IF filter, and/or some pretty fancy signal processing, it will be very difficult to winkle out weak signals.

One of the simplest, and most effective tools in our fight against noise is the loop antenna. Traditionally, a timber (or plastic) frame of perhaps 0.8 square metre, is wound with insulated copper wire, the inductance of which is capacitively resonated, and coupled to the receiver's input. The frame loop has a sharp null running through the axis of the loop, which often allows interfering noise to be placed in the null without serious loss of the wanted signal (see Refs. 5, 7, 8).

However, because of size, the frame loop may be awkward in some circumstances, and is not particularly portable. A reasonable alternative is to use a much smaller ferrite-rod "loop-stick" antenna. Although not as sensitive as the frame (smaller area, therefore more RF gain required), similar nulls are obtained off the ends of the rod.

The following converter circuit is offered as a simple device that gives listening access to the LF region. A reasonably sensitive and selective shielded HF receiver which tunes the 3, 4, 5, or 6 MHz bands is required as "tuneable IF". In operation, the device is remarkably sensitive, and should prove quite satisfactory for reception of amateur signals in the happy event that in due course we obtain an LF band allocation (see Ref. 4 for an excellent source of LF information). Whatever the outcome, the converter allows you to observe propagation characteristics in the 140 to 400 kHz region.

Circuit

See Fig. 1. A high Q coil, wound upon a ferrite rod, couples into the magnetic field component of incoming signals. When the inductance of the coil is resonated at the frequency of the signal, an RF voltage is presented to the high impedance gate of the MPF102 FET amplifier. The 100 pF capacitor is included to by-pass any strong TV signals which may be present.

The amplified signal at the drain is applied to one input port of an NE602 (or SA602 or NE612) Gilbert-cell mixer. An internal crystal-controlled oscillator of 3, 4, 5 or 6 MHz translates the LF band up to a corresponding HF band. For example, when using a 3 MHz oscillator crystal, a signal on 177 kHz will appear on 3.177 MHz (these round-number crystals are available from several of the electronics suppliers as cheap, standard, computer types). IF output signal appearing at pins 4 and 5 is coupled to the tuneable IF receiver via broadband impedance matching transformer T1.

Construction

A suggested construction method is depicted in Photo 1, which shows the prototype housed in a plastic jiffy box measuring 197 x 113 x 63 mm. These are obtainable from several of the electronics merchants. The ferrite rod measures 10 mm dia x 200 mm long (see Parts below). Wind on 165 turns of #24 B&S (0.5 mm) e.c.w. Start and end may be held in place with masking tape. The rod is installed lengthwise in the box, which is drilled exactly rod diameter each side, and held captive with a blob of epoxy cement at each end. Remember to allow for interference-free operation of the variable capacitor.

The variable capacitor is an ordinary two-gang 450 pF per section broadcast type, salvaged from an Australian BC valve set (for years I had believed that these were 415 pF, but most in my junk-box measure about 450 pF). They are not rare items, and may be found at ham-fests, or swapped from radio mates. Make a suitable cursor and dial/knob for the frequency scale.

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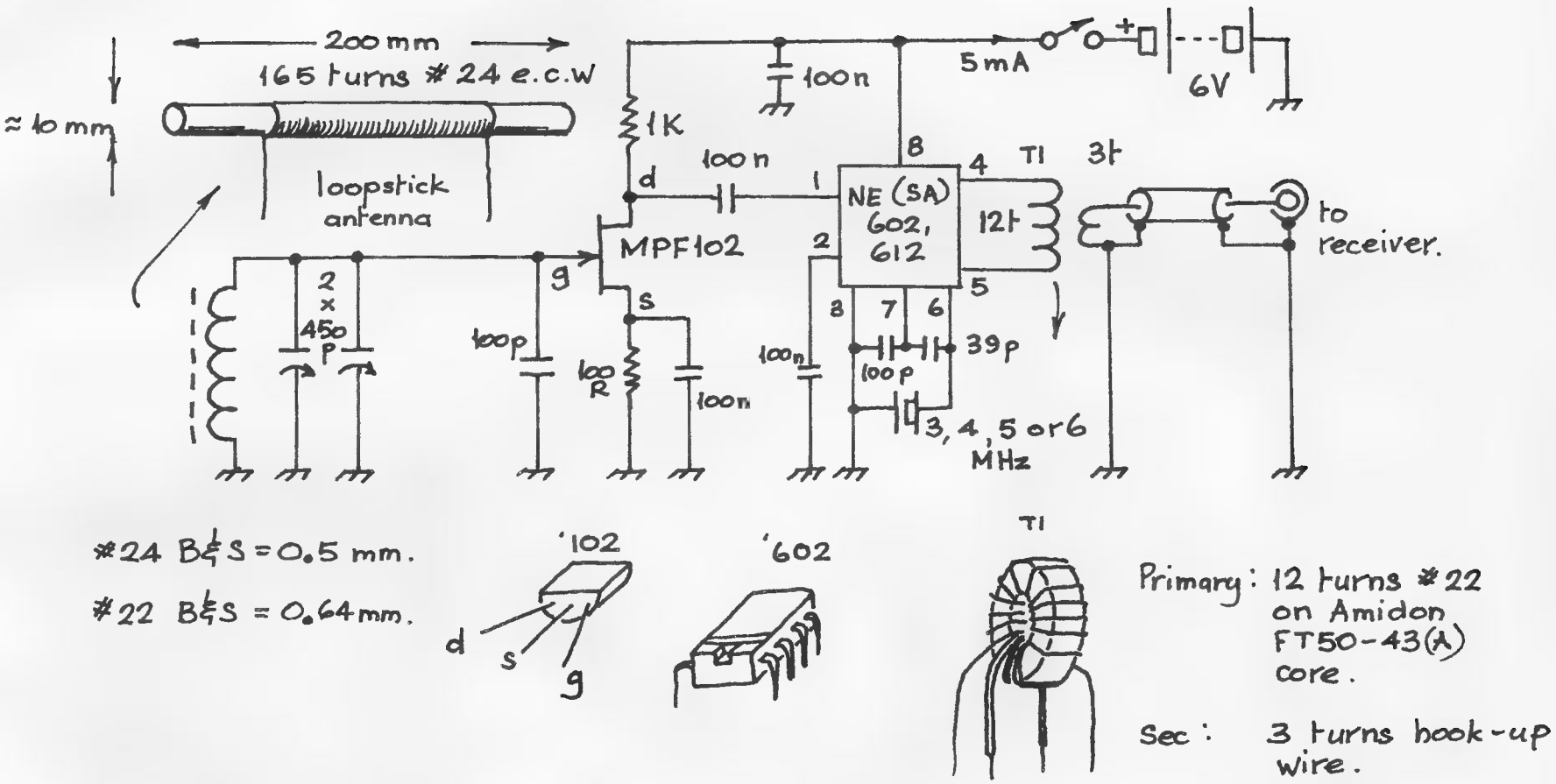

Figure 1: LF Recieving Converter with Loopstick Antenna

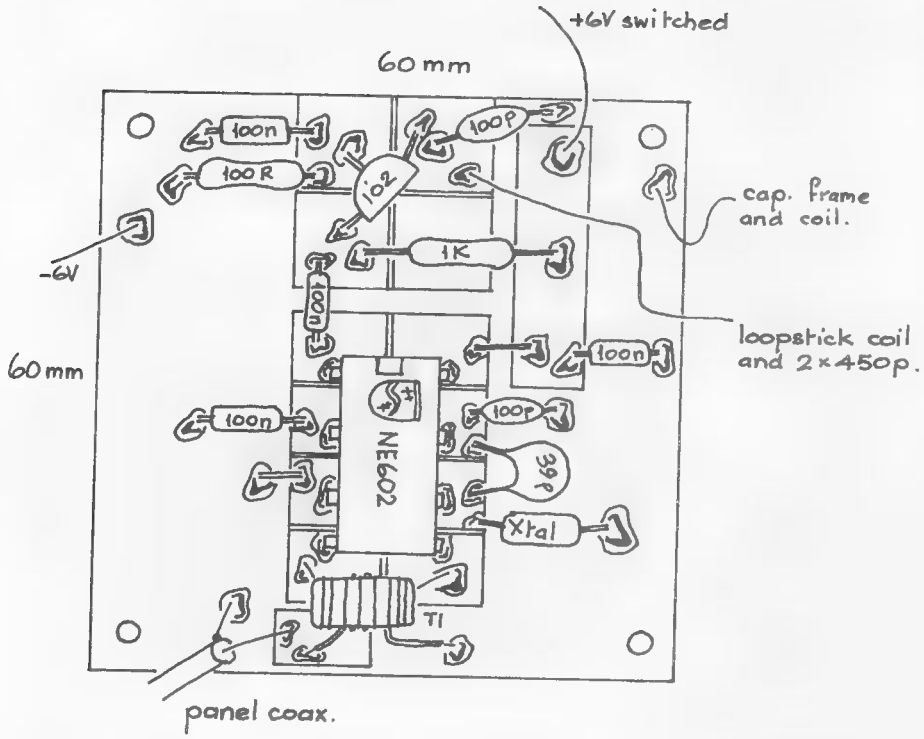

Figure 2: Board Layout

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The circuit is accommodated upon a paddyboard (see Ref. 10), and a suggested layout is shown in Fig. 2. The NE602 is fitted into an 8-pin wire-wrap IC socket (pins gently flared) which in turn is soldered to a substrate board. But any other method that you favour should work, provided that signal connections are kept reasonably short. A battery of four type AA cells in a four cell holder is affixed to the outside of the box with cable ties. Battery switch and output connector are fitted into the front panel.

Operation

Check all wiring and component connections. Connect the converter output to your receiver input using a suitable coax cable, and set the receiver to the appropriate band. Switch on. Tune the receiver to crystal plus about 250 kHz. Adjustment of the variable capacitor should cause a strong sharp peak in noise as the loop-stick is resonated. Search the band for signals, re-peaking as you go. When one is found (probably a navigation beacon with AM Morse call-sign), peak the converter capacitor for maximum response. The set-up should sound "lively", there typically being many beacons found. Their call-signs give a clue to locality. Here near Melbourne for instance, in addition to the local signals, I can easily hear FLI Flinders Island, BHI (Broken Hill), DVO (Devonport) and SMI (Smithfield) airfield beacons. Amateur/experimental transmissions have recently been made from AX2TAR in Moonah, Tasmania on 176.5 kHz. Listen also for ZL signals on about 177 kHz.

Local signal strengths are remarkably constant, and vary little from day to night. At night the back-ground static noise level increases significantly, sometimes making it difficult to hear weak signals. If interference is experienced on a particular frequency, rotate the converter box to place the interfering source in the sharp null.

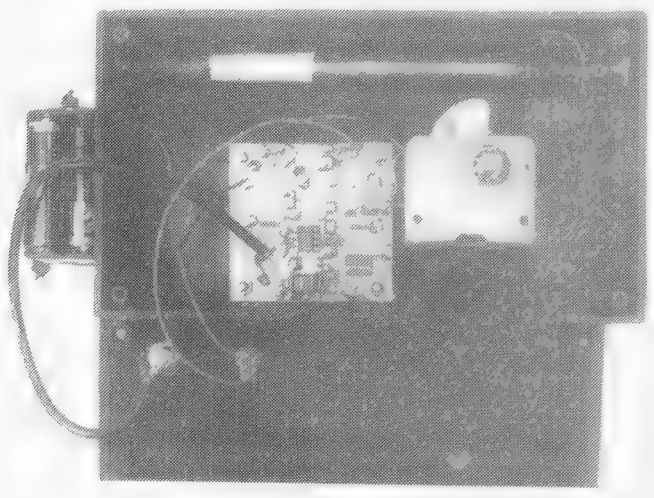

Photo 2: Internal View

Parts

Most of the components are available from the familiar merchants such as Altronics, Dick Smiths, Electronic World and Jaycar. NE(SA)602 chip and 10 x 200 mm long ferrite-rod (other suppliers may have something similar) are available from Electronics world (ph 03 9723 3860- will answer mail orders).

References and Further Information

1. Radio Communication Handbook, 7th edition (Ch 7); RSGB.
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3. Secrets of RF Circuit Design; Carr; TAB Books (from DSE).
4. VK2ZTO's LF Home Page, check out; http://www.zeta.org.au/~ollaneg/aussielf.htm.
5. "Around the Loop"; Marris, G2BZQ, Prac. Wireless (PW) May '95.
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7. "PW Helta- An Experimental Loop Antenna"; Marris, PW Feb. 96.
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An Active Loop Converter For The LF Bands

Lloyd Butler VK5BR

Localised noise interference is a common problem in receiving signals on the Low Frequency (LF) bands. To minimise this noise there should be two essential features incorporated in the LF front end.

The two essential features are

(1) A sharply tuned circuit at the LF frequency. This limits both high level noise and strong signals on other frequencies from cross modulating the desired signal in the following mixer stage. The sharper the tuning, the better this is achieved. Unfortunately many LF converter circuits have broadband front ends.

(2) Use of a tuned loop antenna. Localised noise predominates in the electric component of the noise field. The small loop picks up the magnetic component of received signal and is insensitive to the electric component of the noise field.

Furthermore, because of its directivity, the loop can be rotated to enhance the level of the desired signal relative to other signals or noise which come from a different direction. Also because the loop null is quite sharp, this can be positioned in the direction of the unwanted signal or noise to some advantage. (Reference 1 gives more information on the loop theory).

In the converter which is described, a loop antenna is used as the only tuned inductive element with *positive feedback* applied to increase its effective Q and sharpen up its tuning. This of course is the old trick called *reaction* or *regeneration* used in the early days of TRF receivers to improve selectivity.

With the adjustable reaction control set to a stable point just below the point of oscillation, Q factors of between 1000 and 2000 are achieved. This means an effective 3db bandwidth of around 100 to 200 hertz at 200 kHz.

A switch selects a choice of three frequency bands. The loop specified has an inductance of about 500 uH and using this loop the bands are as follows:

Band 1	**195 to 490 kHz (includes the aeronautical homer beacons)**
Band 2	**150 to 220 kHz (includes the New Zealand amateur band)**
Band 3	**128 to 160 kHz (includes the European amateur band).**

For the following discussion on circuit detail, refer to figure 1 on facing page..

The Frequency Converter

The mixer stage employs the now universally used NE602 package (N2), the output of which is fed to the input of a HF receiver. One way to operate this stage is to operate its local oscillator in a tuneable mode with the output as a fixed 1st Intermediate frequency (IF) fed to the receiver.

That system, which I used in a previous converter (reference 2), necessitates the calibration of the local oscillator tuning dial in terms of the incoming LF. In this new converter, I have made use of the idea that Drew Diamond (VK3XU) used (see ref. 3).

The local oscillator is crystal locked on an even multiple of Megahertz and the 1st IF varies with the incoming frequency so that the receiver is tuned over a range equal to the MHz frequency plus the LF. If the receiver is accurately calibrated, the calibration is simply read off on the receiver dial (or digital display) ignoring the MHz.

In this system, the received frequency at the input of the converter is determined by the frequency tuned on the HF receiver.

For the calibration to be correct, the oscillator MHz frequency must be accurate. Drew used a frequency of 3 MHz. I had available a 3 MHz cheap ceramic crystal and a 4 MHz quartz crystal in the HC25 holder. I started off with Drew's circuit values but found both crystals oscillated at far too low a frequency making the receiver calibration a long way out. (This gets back to the fact that crystals are made to suit a particular circuit constants and when ordering a crystal one should always specify the circuit with the order).

Anyway I settled on the 4 MHz crystal and trimmed my circuit values to make my crystal oscillate on the right frequency (refer values of C16 and C17 in figure 1).

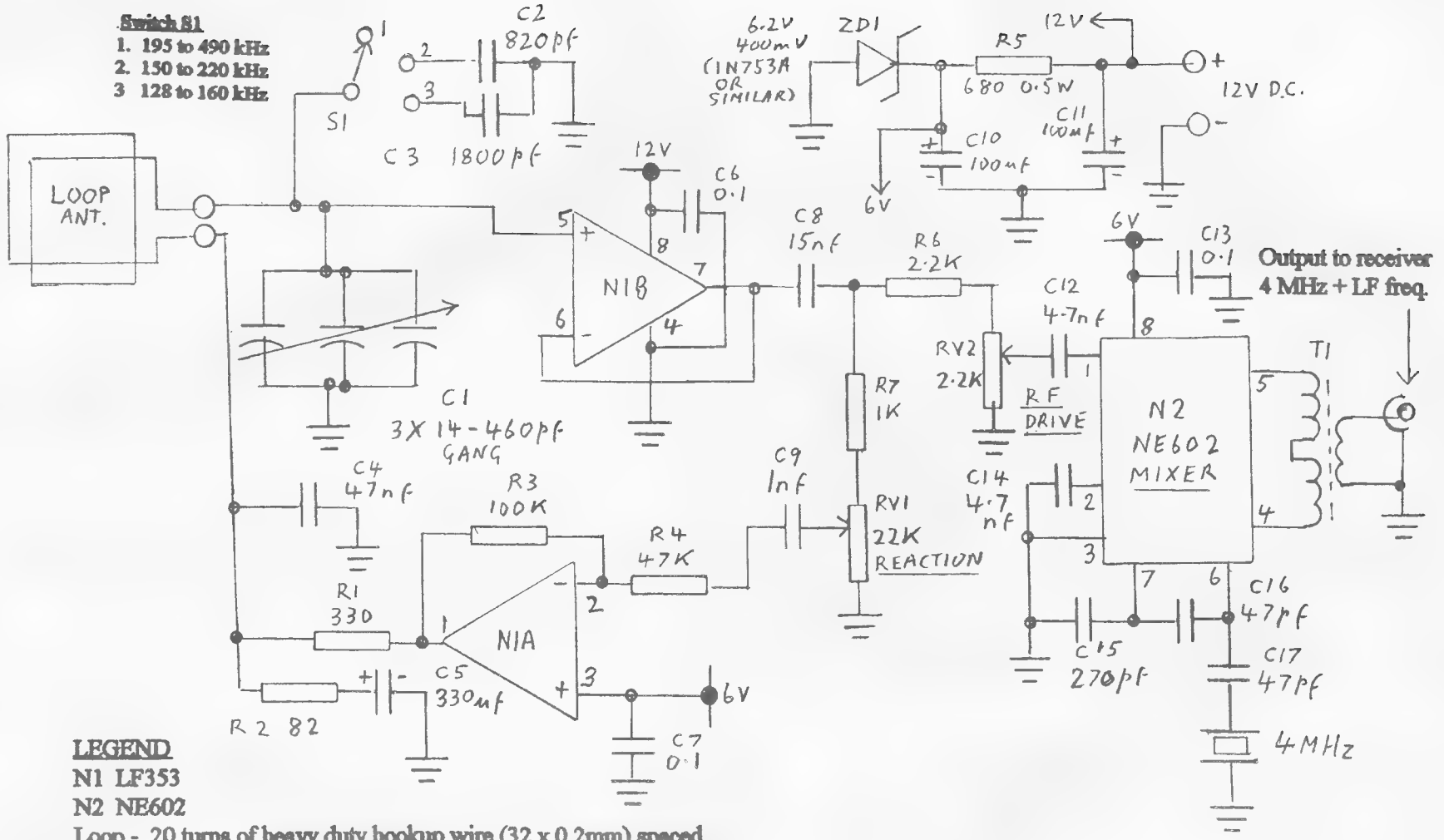
I must point out that the value of these capacitors might not be quite right for some other random crystal.

The Loop

The loop (figure 2) has been successfully used in conjunction with other receiver arrangements and has been mentioned before in my previous articles on VLF/ LF in AR. It consists of 20 turns of 32 x 0.2mm hook-up wire spaced laterally 10 mm apart on a wood frame 0.8 metre square.

It works fine indoors and is connected to the converter via 2 metres of figure 8 flexible cable. For other receivers, coax cable was used with the cold end of the loop at earth potential. However in this receiver, the feedback signal is fed in series with the loop and the colder end of loop is at an RF potential a little above ground level.

The only difficulty I have experienced indoors with the short cable is noise from the fluorescent lights. So I just turn these off. The cable can be extended so that operation is possible outdoors but the extra cable capacitance will limit the



LEGEND

N1 LF353

N2 NE602

Loop - 20 turns of heavy duty hookup wire (32 x 0.2mm) spaced 10mm apart on a 0.8 metre square wood frame. Loop is connected via 2 metres of Figure 8 flex cable.

L1 - 10 turns trifilar wound on a suitable ferite toroidal core (core used was a philips 97050 9mm core mu = 5000).

FIGURE 1 ACTIVE LOOP L.F. CONVERTER

Circuit Diagram

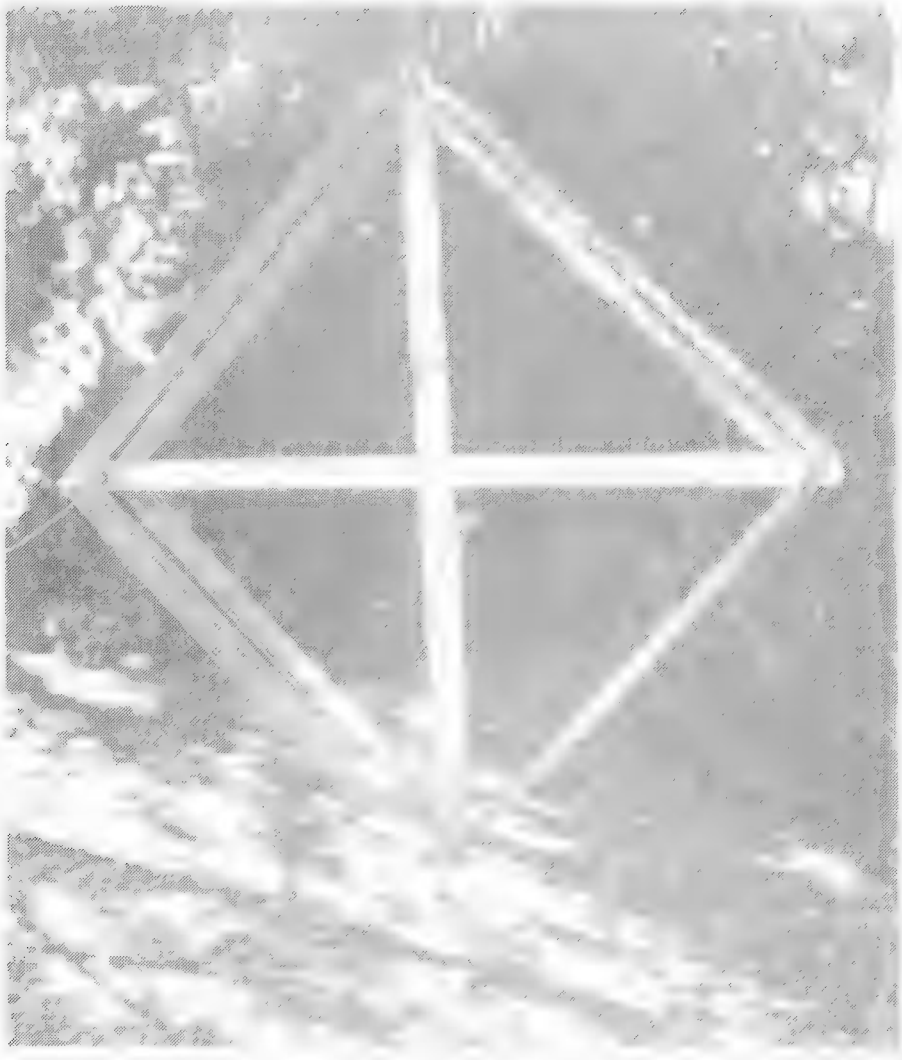


Figure 2 The Loop Antenna

maximum tuneable frequency on band 1. There seems to be little advantage in hanging the loop more than a metre or so above ground or floor level. If kept well clear of surrounding objects it works fine.

The minimum frequency on band 1 is set by the maximum capacity of 3 gang tuning capacitor C1. The maximum frequency on band 1 is set by the loop inherent capacitance plus its feed cable capacitance. The actual minimum and maximum frequencies are of course also controlled by the inductance of the loop. The frequency range is extended downwards by switching in capacitors C2 or C3. Addition of this capacitance to lower the frequency progressively reduces the range achievable by the adjustment of C1.

With the feedback adjusted for high Q, the tuning is very sharp and a vernier drive coupled to C1 is desirable.

The Loop Interface and Feedback Circuit

The loop is interfaced by one half of twin MOSFET opamp LF353 (N1B) which operates as a voltage follower and which presents a high input impedance across the loop.

A portion of N1B output is fed back into the loop across capacitor C4 via the second half of the opamp N1A. The amount of feedback or reaction is controlled by the setting of potentiometer RV1.

The circuit is an adaptation of a circuit used in a previous simple VLF/LF receiver which I constructed (ref. 4). The reason for the inclusion of R2 might not be too clear but it was added to the circuit in the earlier receiver to stop some undesirable effects caused by the rise in impedance across C4 at very low frequencies..

The output of N1B is coupled to the input of mixer N2 via drive control potentiometer RV2. This was included so that the RF drive could be reduced in the event of strong signals reaching the mixer input at sufficient level to cause cross modulation. The NE602 package has a fairly low third order intercept point which means intermodulation products can easily be produced at moderately high signal levels. (This was discussed in a previous article, reference 2).

The signal levels induced into the loop are much lower than for a long antenna wire and in the practical testing out the unit, I didn't actually notice any problem here. For my location, RV2 might well be an unnecessary inclusion but it could be needed if the converter is operated a bit closer to a local station.

Powering

The converter operates from a 12 volt DC supply which directly feeds the dual opamp N1. A 6 volt rail is derived with zener diode ZR1 and R5 and this is used for mixer N2 and to centre set the operating points of amplifiers N1A & N1B. The 12V load current is around 13mA. I operated the unit from a bench power supply but with that load current, a 12V bank of AA cells could be used.

Construction

At these low frequencies there are no real problems of lead lengths or inter-circuit coupling.

Minor components (integrated circuits, resistors and capacitors) were mounted on a piece of blank experimental circuit board made for DIL packages. A aluminium box housing the components had to be large enough to accommodate the three gang tuning capacitor and the large dial of the re-cycled vernier drive I coupled to it.

Almost any connector can be used for input and output. I used a twin REC socket (a twin version of the PL259) for the loop connection and a BNC connector for the 4 MHz output.

There is also nothing very critical about the design of the toroidal output transformer T1 and in fact the one I used could do with a few less turns on the secondary to suit the expected low input impedance of the usual HF receiver..

Operation and Tuning

Procedure is as follows: Connect the output of the converter to the HF receiver via a shielded line (coax cable or shielded wire). Hang the loop in a free space and connect its lead to the converter input. Connect the 12V supply and apply power.

Set the receiver tuning to 4 MHz plus the required LF frequency. Set the RF drive control to maximum. Ensure that the Reaction Control is set well below the point of input stage oscillation. (With a little practice one can recognise sounds from the receiver which indicate the oscillation point).

Rotate the loop tuning control (C1) for maximum noise from the receiver. Advance the reaction control as far as possible in the stable state below the oscillation point. Carefully check that the loop tuning is set at the centre of its resonance peak. If a signal is available on the tuned frequency, the peak could be indicated by maximum reading on the receiver signal strength meter. (There are plenty of aeronautical beacon (NDB) signals available for a test).

Rotate the loop antenna 360 degrees and the signal can be heard to fade in and out as it passes through the two peaks and the two nulls of the loop radiation pattern.

It should be noted that if the reaction control is advanced to the point of oscillation, the loop aerial can operate in reverse to radiate a signal at the frequency of oscillation. However this is not too much of a worry as the radiation resistance of the loop is so low that almost all of the energy generated is consumed in the loss resistance of the loop.

One could expect that the signal would be of such a low level, it would hardly be detectable over the back fence.

To quote some figures, I have calculated the radiation resistance of the loop to be close to 1 micro-ohm. The RMS voltage developed across the loop in the state of oscillation has been measured as a little less than 5V. The reactance of the loop at 200 kHz is around 600 ohms so that for 5V, the current through the loop is 8.3 mA.

Power radiated is this current squared times the radiation resistance which gives a power radiated of 68 micro-micro-watts, quite an insignificant figure. However, to minimise possible localised interference, one should avoid operation in the state of oscillation.

Performance

Correctly tuned up the converter separates weak signals out of the noise as good as anything I have tried out at my location. The only limitation is that is difficult to quickly scan the band with the front end so sharply tuned.

It is really a two hand operation. One has to track the tuning with one hand at the converter with. the other at the HF receiver. If we know what we are looking for and know the frequency then there is no problem.

From the loop formula (ref.1) my loop is calculated to give an induced voltage of 0.05 uV per uV/metre of signal received at.200kHz. This is multiplied by the Q factor of the loop at resonance. Assuming an effective Q of 1000, the voltage at the input of amplifier N1b is 50 uV per uV/ metre of signal at 200 kHz.

The conversion transfer ratio between the input of N1b at 200 kHz and the mixer output at 4.2 MHz was measured as 0.15 into a 50 ohm resistive load and 0.75 loaded into my FRG7 receiver input (obviously the antenna input impedance of the FRG7 is much higher than 50 ohms at 4 MHz).

From the above, when the loop feedback is set for a Q of 1000, the converter sensitivity at 200 kHz is 7.5 uV of converted output per signal strength of 1 uV/meter when the output is loaded into 50 ohms. Loaded into the FRG7 receiver, the figure is 37.5 uV per uV/meter.

Summary

A simple LF converter has been described which tunes the range of 128 to 490 kHz. This includes the bands allocated to European, British and New Zealand radio Amateurs and the Australian/New Zealand aeronautical non directional beacons.

The converter makes use of the noise reduction features of the small loop antenna which essential operates on the magnetic component of the received EM wave to the exclusion of the electric component which is predominant in local noise.

The loop is the only tuned element in the unit and feedback (or regeneration) is applied to the loop circuit allowing an increase in Q factor to around 1000 to 2000. This narrows the bandwidth, improving the adjacent channel rejection and reducing the susceptibility of the the mixer stage to cross modulation from strong unwanted signals and high level noise.

The mixer oscillator stage is crystal locked at 4 MHz so that the host HF receiver is simply set at 4 MHz plus the LF frequency. The LF is simply read on the receiver calibration ignoring the 4 MHz.

References

1. Lloyd Butler VK5BR - VLF-LF and the Loop Aerial - Amateur Radio, August 1990.
2. Lloyd Butler VK5BR - The bandwidth Limiting LF Converter Simplified Amateur Radio, January 1994.
3. Drew Diamond VK3XU - Simple LF Converter - Amateur Radio. December 1995
4. Lloyd Butler VK5BR - A Simple Regenerative VLF-LF Receiver Amateur Radio, January 1992.

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The Active Loop Converter at VLF

The Tuning Range of the Converter can be extended down to VLF with the addition of a few components

Lloyd Butler VK5BR

The original active converter as published in the July 2000 issue of Amateur Radio was made to tune the LF range of 128 to 490 kHz. Components have since been added to enable tuning down to around 12 kHz. The following text describes how this was done.

Circuit Detail

In previous loop circuits described by the writer (references 2 & 3), extension of loop tuning down to VLF was achieved by progressively switching in fixed shunt capacity across the loop using capacitance values as large as 0.47 microfarads. At the lowest frequencies, loop resonance was available at a number of spaced fixed frequencies with the shunt variable capacitor of 1350 pF having little effect . The system was workable between these spaced frequencies without fine tuning because with such a large capacitance across the 500 uH loop, the tuning response curve was very broad.

However the active loop circuit is aimed at very high values of Q which makes the tuning very sharp. Hence there is a need for fine tuning adjustment. So in this circuit, switching in of fixed shunt capacitance is limited to lower values and series inductance is added instead of large capacitance.

The circuit modifications are shown in figure 1. The original circuit provided the following tuning ranges:

Switch S1 pos. 1 - 195 to 490 kHz (no fixed capacitance)

" pos. 2 - 150 to 220 kHz (C2 in circuit)

" pos. 3 - 128 to 160 kHz (C3 in circuit)

A fourth switch position has been added to S1 which switches in C18 to provide tuning of 110 to 130 kHz without any series inductance.

A further addition is the inclusion of switch S2 which allows the progressive addition of series inductance by the selection of switch positions 2, 3, 4 & 5. By suitable selection of fixed inductance and capacity using both S2 and S1, peak tuning of the circuit using variable capacitor C1 is achieved for a continuous frequency range down to 12 kHz.

Apart from the ability to properly peak the loop circuit, the converter at VLF is far more lively loaded with inductance than with the shunt capacity. This probably results from the higher L/C ratio and the higher resultant static Q.

The inductors used are 2.2, 10, 22 & 50 mH. The 2.2 and 10 mH inductors are miniature chokes available from Dick Smith Electronics. The higher value inductors are ferrite pot cores which were retrieved from somewhere else. The 22 mH one was already wound for that inductance but the 50 mH one had to be rewound. As the characteristics of the pot core was not known, a test winding of a given number of turns was first made and the inductance measured. Given that inductance is proportional to the square of the turns, the correct number of turns for the required inductance was easily calculated form the initial number of turns and the measured inductance.

The effect of high Q

The publishing of the original article (ref. 1) has raised some discussion on the effects of running a very high loop Q. Here are some of these effects:

1. If the Q is set too high on AM or SSB the bandwidth could be too narrow and speech quality could be impaired.
2. Higher Q can be used with keyed CW than for speech because the bandwidth required is less. However there can still be an upper limit when the loop as a tuned circuit tends to ring and destroy the keying intelligibility.
3. Even a moderate value of Q might be sufficient to prevent a noise blanker circuit working in the receiver. Noiseblankers only work on impulse type noise i.e. high level pulses of short duration such as generated by spark discharge. The blanker works by closing down the receiver for the short duration of the pulse. If the pulse is fed through a high Q circuit, the short duration, high level nature of the pulse is destroyed and the blanker can't operate. Here is a case for having a switch to connect in a series resistor with the loop to reduce Q to a very low value. For broadband noise, use the maximum Q to reduce bandwidth. For impulse noise it might be an advantage to switch in the resistor and use the blanker with wider bandwidth. .
4. The ratio of signal level to noise generated by the loop interface amplifier can be improved by raising the natural loop Q to raise signal voltage. However this ratio is not improved by the enforced higher Q due to the feedback as the amplifier noise is itself within the feedback loop. The main advantage of the feedback is the lowering of the noise power in the narrowed bandwidth created by the higher Q. It also reduces the chance of high level signal or noise outside the received signal passband from causing intermodulation in the mixer stage.

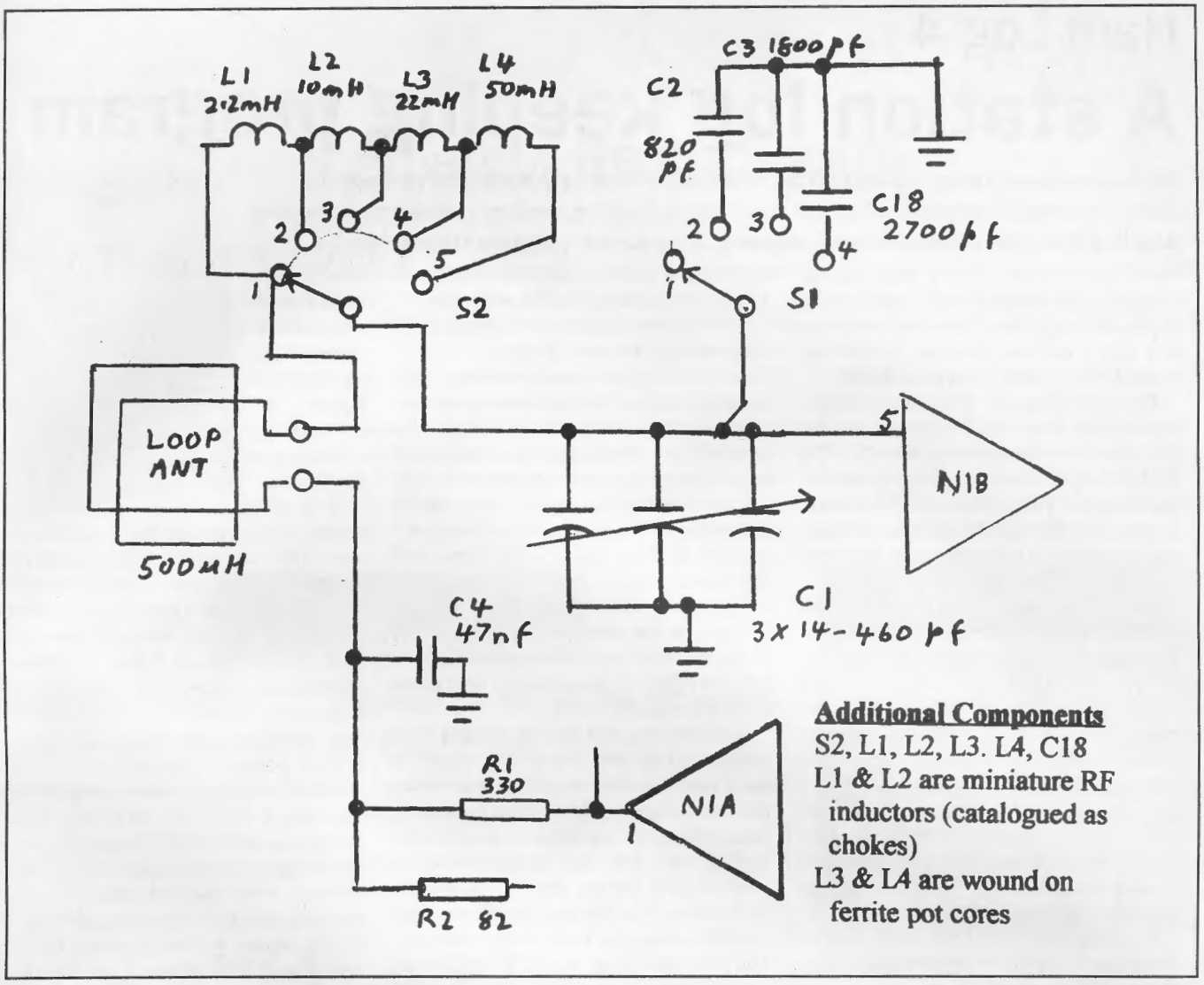

Figure 1

On this subject, signal level into the amplifier can also be raised by increasing the number of turns or increasing the area of the loop. However an interesting point on the loop's own noise has been raised in an article from Break-In (ref. 4) which was kindly sent to me by Richard Rogers VK7RO. The ratio of signal level from the loop to the noise level generated from its own loss resistance is improved by increasing area but increasing turns makes no difference to that ratio. On figures shown, the loop noise can be comparable in level to that of the incoming atmospheric noise if the loop area is too small. To ensure that the noise floor is set by atmospheric level and not the loop itself, the writers suggest that for a circular loop, its diameter should not be less than 1 metre. .

Summary

The main purpose of the article has been to describe how the Active LF converter is modified to extend its tuning down into the VLF region.

Before concluding we have also digressed a little into effects of enforcing the higher operating Q and commented on one factor affecting S/N ratio in the loop itself.

References

1 An Active Loop Converter for the LF Bands - Lloyd Butler VK5BR Amateur Radio, July 2000.

2. VLF-LF and the Loop Aerial - Lloyd Butler VK5BR, Amateur Radio, August 1990.

3. Modifications to the Bandwidth Limiting Converter to include VLF, Lloyd Butler VK5BR, Amateur Radio, March 1994.

4. LF Scene - Andrew Corny ZL2BBJ & Bob Vernall ZL2CA, Break-In, July 1997.

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A Single Sideband Modulator for the LF Transmitter

(The Phasing System of SSB revisited)

Lloyd Butler VK5BR

The February, 2000 issue of *Amateur Radio* included my article on *An Experimental Low Frequency Transmitter (ref. 1).* The article was published in anticipation of the approval of a new amateur band in the LF region. At the time of preparing this article which follows, approval was still being sought. There was also the question that if such a band was approved, would it allow some mode of speech transmission?

In anticipation of a need for speech operation, I decided I would design a speech modulator for the already built LF transmitter. With the limited band space available in a band in this part of the radio spectrum, a single sideband (SSB) system seemed preferable to the wider bandwidth AM system. So this is what I have built and what I am about to describe.

The simplest way to produce SSB for the LF transmitter might have been to heterodyne down the RF output of the amateur station HF transceiver. However this might have put some limitations on the utility of the LF equipment for use at a unique site away from the amateur station and I decided to build a stand alone modulator which could connect into the LF transmitter.

These days, most SSB transmitters use the filter method where double sideband is produced with carrier balanced out and one sideband rejected by feeding the other through a steep skirted bandpass filter. The filter is fixed in frequency and frequency transmitted is derived by a heterodyne process. The filter is normally centred in the HF region and the usual amateur method to make such a filter is to use a ladder network with quartz crystals of the same frequency. For application with the LF transmitter, the fixed frequency SSB signal, could be heterodyned down to the required low frequency.

An alternative method of producing a single sideband is the phasing system. For this system, there are two modulators which balance out the carrier signal fed to them. The carrier to one is fed 90 degrees out of phase to the other. Audio signal generated by speech is fed to both modulators, the signal fed to one being 90 degrees out of phase with the other over the whole speech frequency range. Balancing out of one sideband using this system can be illustrated with the aid of vector diagrams. A description making use of these diagrams, as given in the RSGB

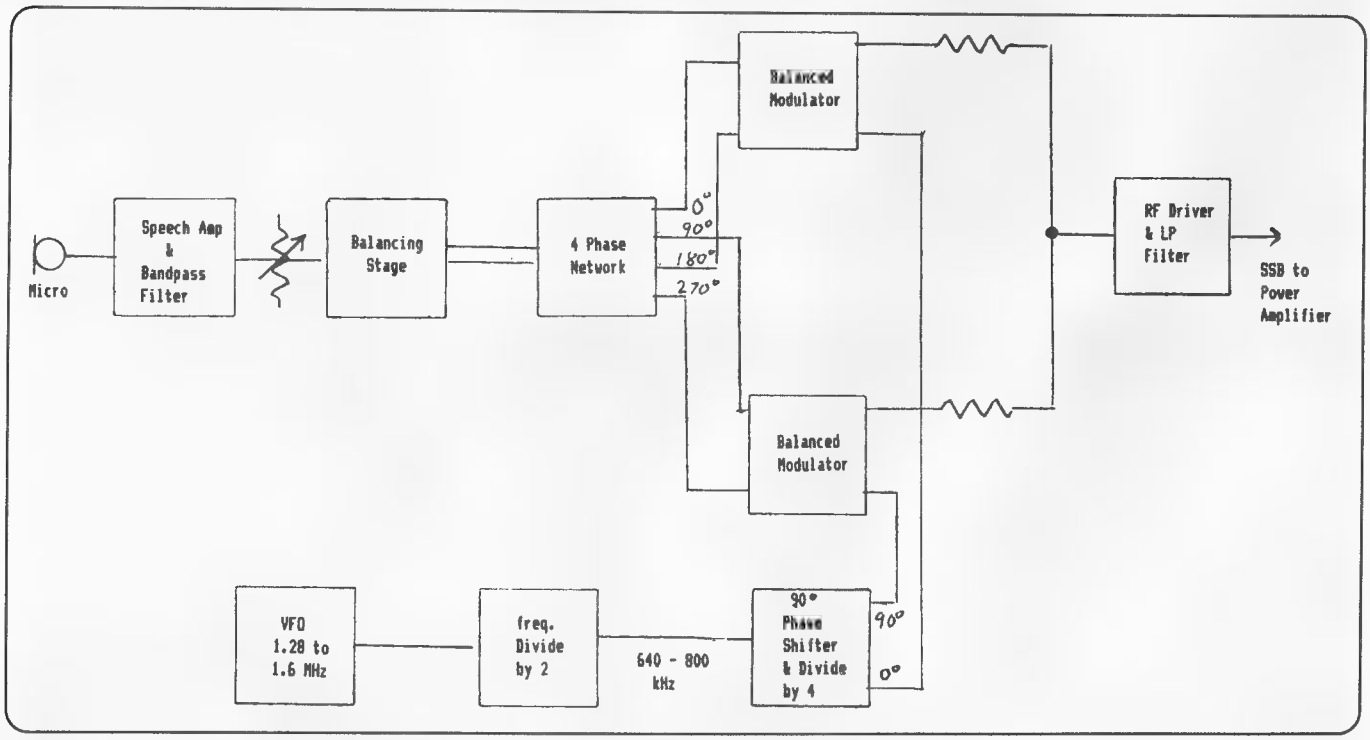


Figure 1: Single Sideband Modulator — Schematic

Radio Communication Handbook, is included in an appendix at the end of this article.

One feature of the phasing system is that it can be made to operate over a wide range of frequencies without any tuned circuits, selective frequency circuits or heterodyning. For the LF transmitter, this system provided some attraction as the whole process could be done at the LF baseband and cover the whole transmitter frequency range of 160 to 200 kHz without any selective frequency elements.

It seems that the phasing system might have lost favour because of difficulties in making a satisfactory audio phase shift network. Whilst a 90 degrees phase shift can easily be achieved at a single radio frequency, it is somewhat more difficult to maintain a constant 90 degrees phase shift over the whole speech frequency spectrum. Some networks used for the audio phase shift have required high precision components and this has discouraged assembly by radio amateurs. Because of this, my first job was try out an audio phase shift network. As it turned out, this proved to be no problem. Furthermore, I had previously experimented with crystal ladder filters as used in the filter type system (Ref. 2) and my conclusion was that it was simpler to get operating the audio phase shift network in the phasing type system than the ladder filter in the filter type system. Also because of the quartz crystals, the component cost of the ladder filter was greater. With this in mind and with consideration of the advantages discussed in the previous paragraph, I decided to build the modulator around the phasing system and the arrangement figure 1 evolved.

The Audio Phase Shift Network

The circuit of the audio phase shift network used is shown in figure 2. This is a design published in issues of both the ARRL Handbook and the RSGB Radio Communication Handbook and is referred to as the *polyphase network* by RSGB. Acknowledgement of design is given to M.J.Gingell by RSGB and HA5WH by ARRL. It requires 24 resistors of the same value and 6 different value groups of capacitors, each capacitor in its group the same. This is a lot of resistors and capacitors but according to the documentation, ordinary 10% tolerance components can be used to achieve constant phase shift over the speech range of 300 to 3000 hertz , with a performance of 60 dB of opposite sideband attenuation.

The network is fed from a low impedance balanced source and gives a four phase output of 0, 90, 180, & 270 degrees. From this, two outputs, 90 degrees apart, can be either balanced or unbalanced.

Despite the large number of components, it didn't take me long to assemble them on a piece of matrix board just as they are laid out in the circuit diagram. I put in a matrix pin for

Continued on page 15

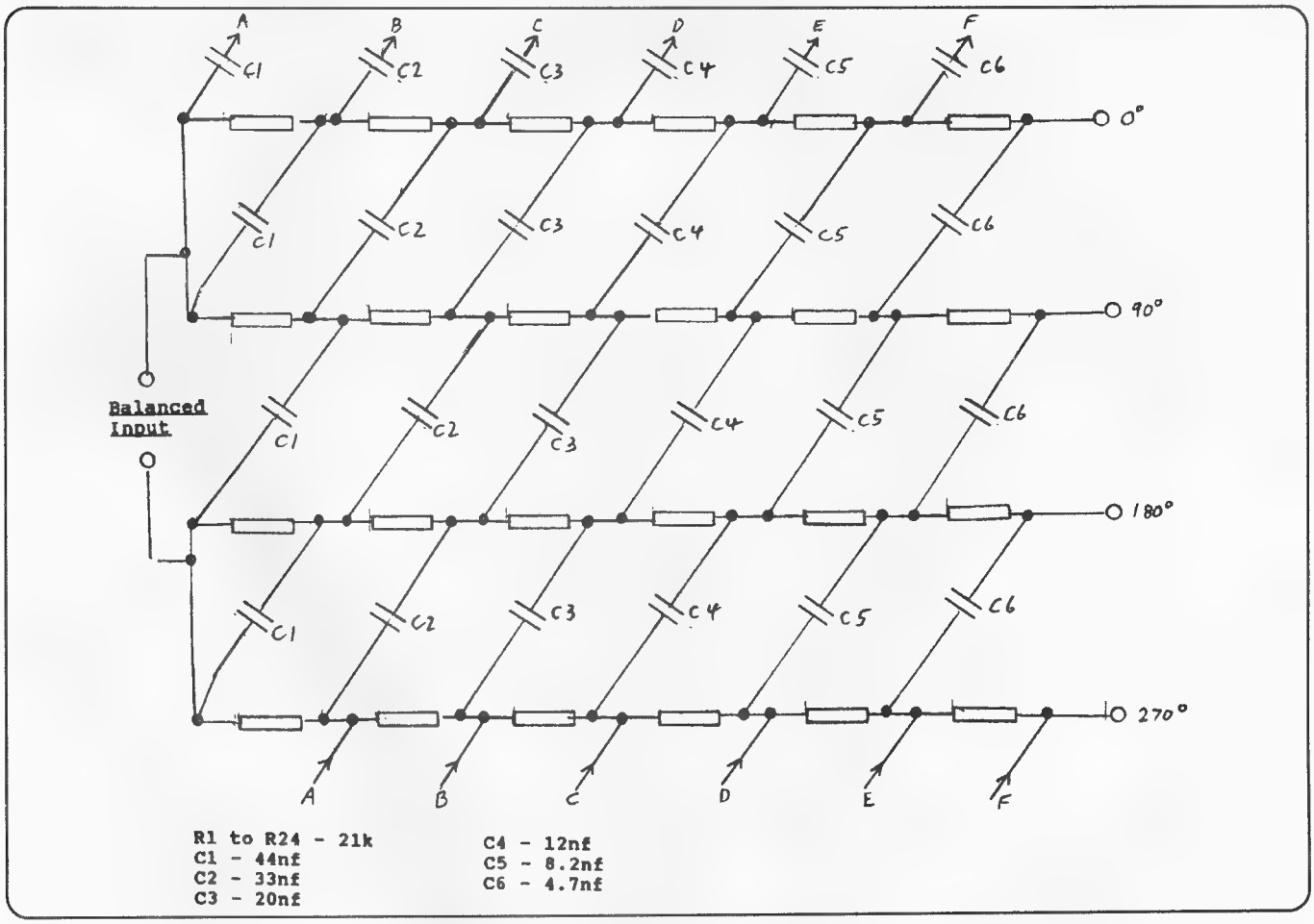


Figure 2: Audio Polyphase (4 Phase) Network

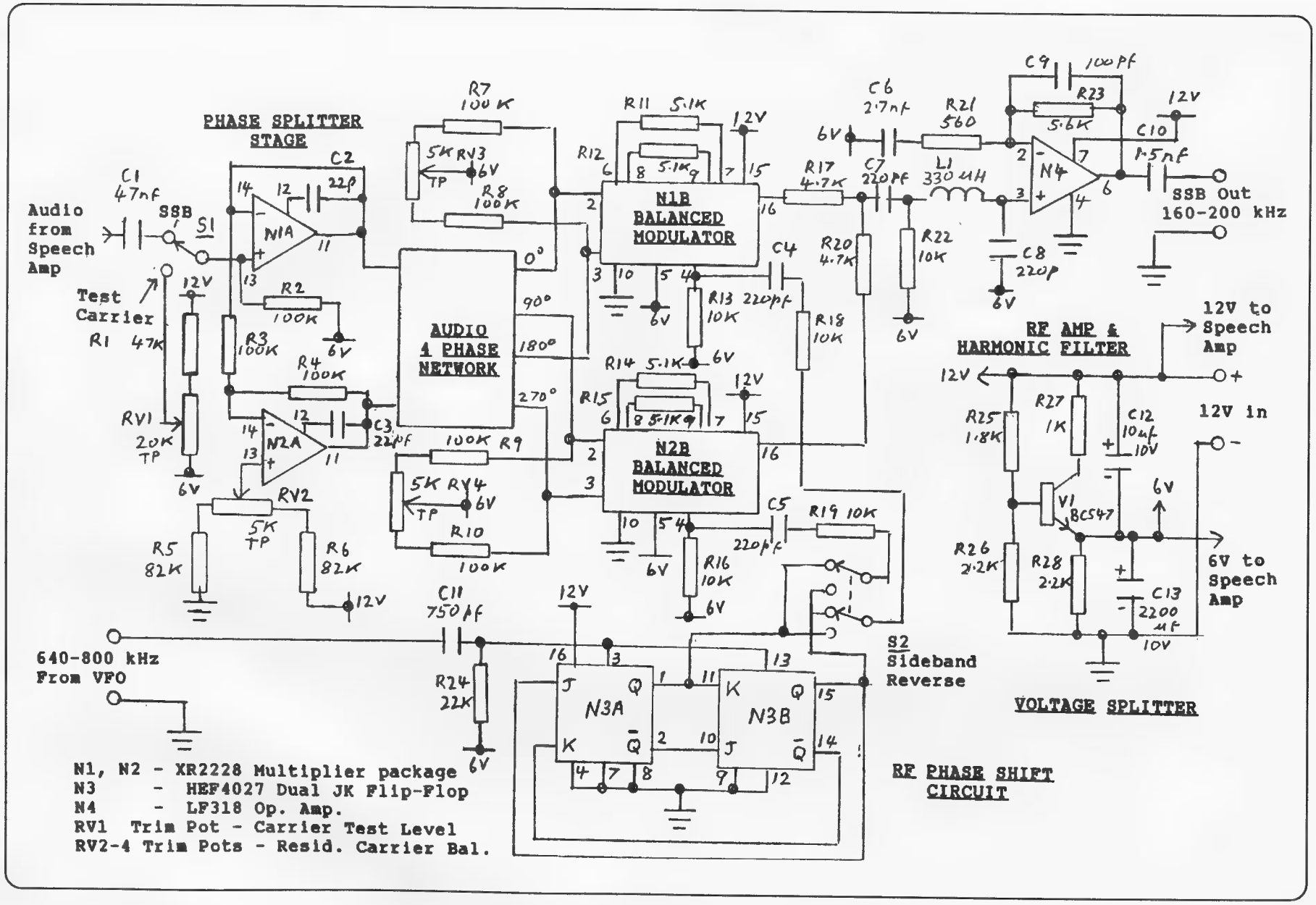


Figure 3: Single Sideband Modulator, General Circuit Diagram

Continued from page 13

each component junction and soldered the components in. Checking it out over the speech frequency range is simple. An audio oscillator is fed to the input via a balancing transformer. The outputs are checked for correct phasing and equal amplitude using any two of the outputs fed to the two Y inputs of a dual trace CRO. Phasing can be carefully scaled using the CRO graticule. For a single trace, one output can be fed to the X amplifier and the other to the Y amplifier to form a vector trace.

As far as I was concerned, I just wired the right value components in and it all just worked like a charm. So the audio phase shift network was no real problem.

The Single Sideband System

A Block diagram of the single sideband system is shown in figure 1. Circuit detail is shown in figure 3. The main elements of the system are a speech amplifier, the audio phase shift network with balanced driver circuit (N1A,N2A), two balanced modulator stages (N1B & N2B), an RF carrier phase shift circuit (N3) and an output RF driver stage incorporating a lowpass filter (N4).

A number of different well known integrated circuit packages such as the MC1496, NE602 and the SL1640 could have been used as balanced modulators. However I happened to have a number of XR2228 Monolithic Multiplier packages and two of these (N1 & N2) are used for these functions. These devices have balanced X and Y input circuits, a balanced output and a circuit arrangement which looked ideal for a balanced modulator. They can also handle frequencies up to around 3 MHz , well above our LF range.

The XR2228 packages also include an operational amplifier each (N1A & N1B) and the pair of these are used to form a balanced low impedance driver for the audio phase network. The amplifier outputs are directly coupled through the network to the X inputs of the balanced modulator sections of the packages (N1B & N2B). Precise DC balance of the complete circuit (necessary to set to for best carrier rejection) is set by trimpot RV2. In retrospect, my thoughts are that it might have been better to use a separate op amp package for the driver as the arrangement resulted in the concentration of a lot of components around the two XR2228 units.

Concerning residual carrier balance, a later addition was the inclusion of trimpots RV3 and RV4 which allow individual adjustment balance of the two balanced modulators and further improvement in the rejection of residual carrier.

A 90 degree phase shift for one of the RF carriers can easily be achieved with simple reactive circuits but this system is somewhat confined to a single frequency. Instead, a circuit using two type D or JK flip-flops can provide two outputs 90 degrees apart for any frequency the flip-flops can handle. For this function, LOCMOS dual JK flip-flop type HEF4027 (N3) has been used. One characteristic of the circuit is that it requires a drive frequency four times the carrier frequency so that for the 160 to 200 kHz transmitter, we need 640 to 800 kHz drive from the VFO. Change between upper and lower sideband is simply achieved by reversing the output leads from N3 which feed the two balanced modulators. Switch S2 is provided for this purpose.

The outputs from the two balanced modulators are combined at the junction of R17 and R20. The single sideband output is insufficient to drive the input of the transmitter and amplifier N4 raises the output level by a factor of 10. The output from the modulators contains higher order frequency components and L1-C8 and R23 -C9 provide a frequency roll-off above 200 kHz to attenuate these components. This is are the only frequency dependent section of the SSB system, limiting operation much above 200 kHz.. Higher order frequency components are further attenuated in the low-pass filter at the output of the transmitter.

As a matter of interest I did carry out some limited tests to see how high a frequency the system could be made to work. (Of course not including the output filters just discussed). I found I could generate single sideband at frequencies as high as 3.5 MHz, limited probably by the characteristics of the XR2228 packages. I suspect the modulators could be made to go higher using packages such as the NE602. Further to that, higher frequencies could be achieved by heterodyning.

The circuit can be switched from SSB to constant carrier for testing or for CW mode by operating switch S1. It achieves this by unbalancing the modulators to allow carrier to get through. The level of carrier is determined by the degree of unbalance set by trim-pot RV1. The switch also disconnects the speech amplifier so that modulation cannot take place. Whilst I haven't allowed for it in the switching, it is only a matter of shorting out this part of the switch to allow the speech signal to reach the modulators with the carrier on and we generate amplitude modulation.

The Speech Amplifier

The speech amplifier is shown in figure 4. It uses two amplifier stages to raise the speech level from the microphone sufficient to drive the input of N1A in figure 3. Its overall voltage gain is close to 2000. The output level is set by potentiometer RV5 which is mounted as a front panel control of the modulation level. Input sensitivity is suitable for a typical dynamic microphone.

The amplifier also includes second order components to achieve a frequency roll off below 300 Hz and above 3000 Hz. This inclusion of some attenuation outside the normal speech range seemed desirable as the audio phase shift network is designed for constant phase difference between its outputs only over the 300 to 3000 Hz range. If any speech components outside this frequency range pass through the network, the phase relationships could be different which could cause generation of opposite sideband.

A popular choice of an amplifier package for the speech amp would have been the uA747 dual op amp. However I have accumulated a multitude of type LM349M which have four amplifiers in the one package. The only reason I instead selected the LM349 for this circuit is that I thought I had better start making some use of these.

The input connection for a microphone is a tip/ring/sleeve stereo type socket which is my standard for microphones in my shack. The tip is wired to a terminal outlet for use as Push-to-talk (PTT) if required later for receive/transmit control.

Power Rails

The modulator circuitry (figure 3) and the speech amplifier circuitry (figure 4) are operated from 12v derived in the transmitter unit and initially provided just for the VFO. A further rail of 6V is

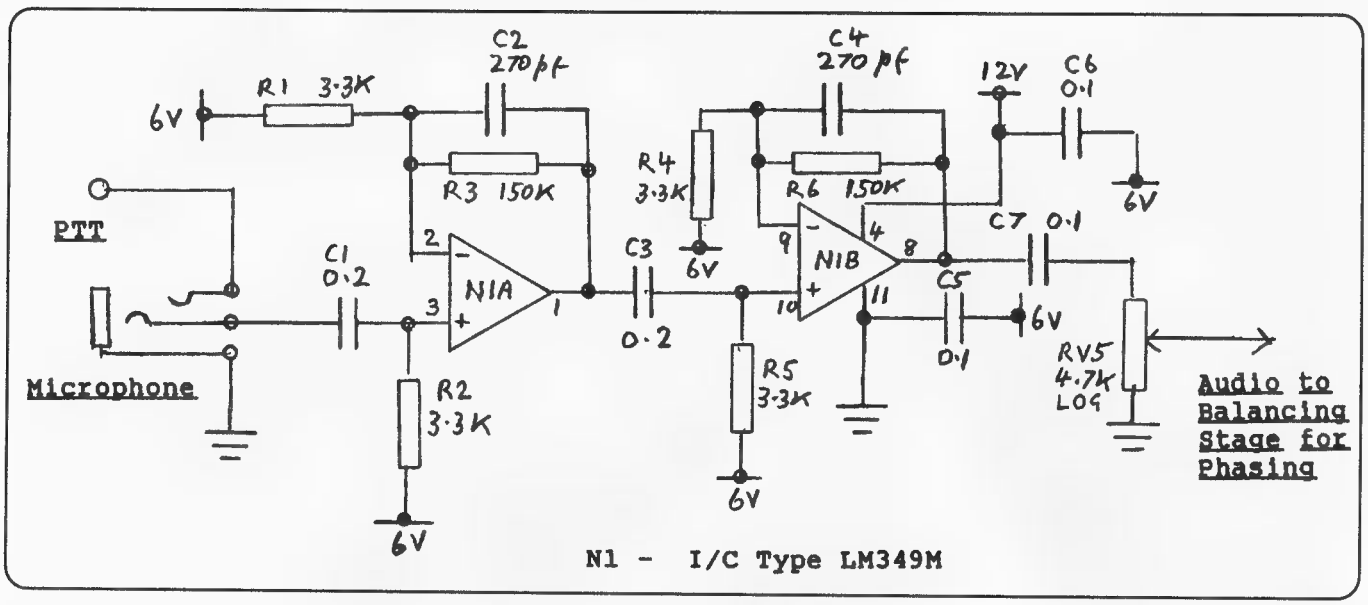


Figure 4: Speech Amplifier

derived by V1 circuit in figure 3 to provide a centre voltage which sets the operating points in the various circuits.

The Variable Frequency Oscillator (VFO)

The VFO is described in my previous article on the transmitter. It initially operated at 10 times the transmitted Low Frequency but this was later changed to 8 times. Some time had elapsed between when the transmitter was built and when I decided write about it in AR. I had forgotten about the change and wrote it up in the article as 10 times. However if one carefully examines the divider circuit following the VFO, as published, it is clearly a divide by 8 circuit. My apologies for that error.

Because the RF phase shift circuit in the sideband unit uses an RF drive signal 4 times the suppressed carrier frequency, an output from the VFO is now required at only half the VFO frequency. The original HEF4017 counter was replaced with a HEF4024 counter which was connected to give two outputs, one divide by 2 and the other divide by 8, the latter of which was fed through the existing sine shaping filter. The circuit detail is shown in figure 5. If the new SSB unit is used, the divide by 2 output is connected into RF phase shift flip-flop circuitry input in the modulator. If it is desired to operate the transmitter in its original CW mode and discard the modulator unit, the divide by 8 sine wave output at 160 to 200 kHz can be directly wired to the transmitter power amplifier input.

Alternatively, to operate CW when the modulator is left connected in circuit, switch S1 (figure 3) is operated to generate the 160 to 200 kHz signal fed to the transmitter via the unbalanced modulators.

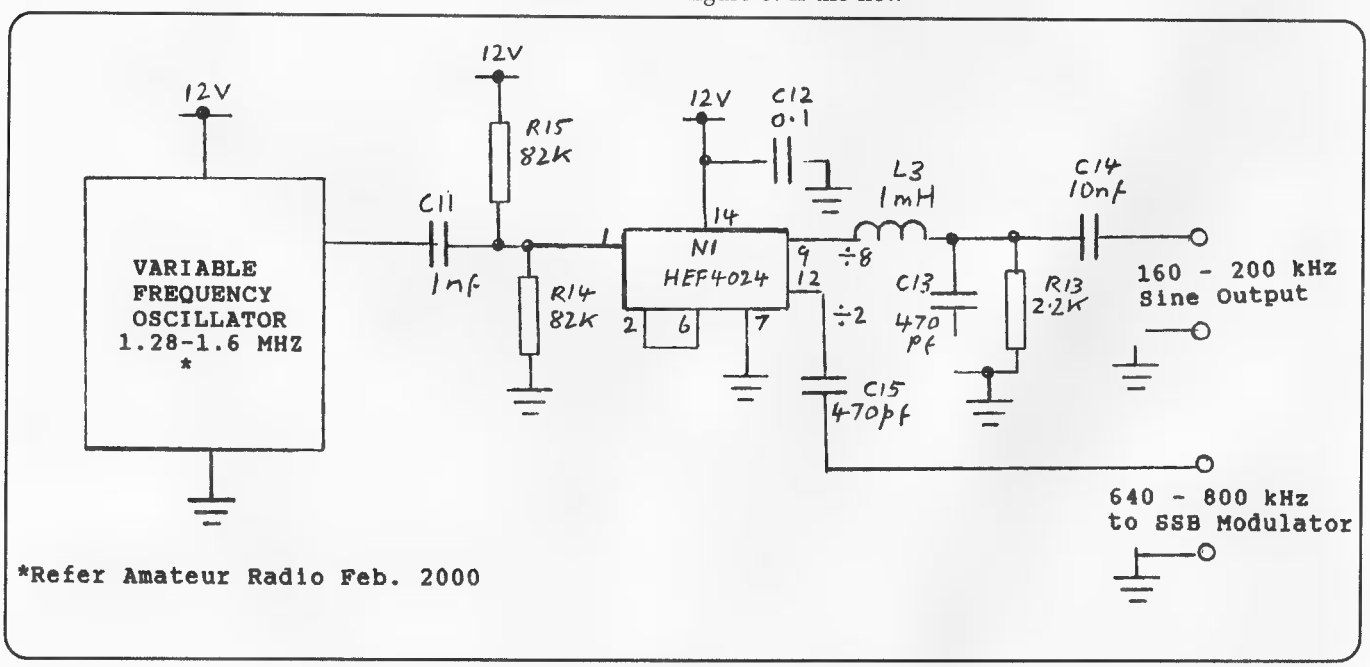


Figure 5: VFO Divider Circuit

Hardware

The integrated circuit packages and associated resistors and capacitors are hard wired on matrix board. The unit is mounted in a small metal box with control switches, potentiometer RV5 and the microphone jack, all on the front panel. It is a stand-alone unit so that the transmitter amplifier and VFO can be used with it or without it. This way, the transmitter can be used on its own for its intended earlier purpose as a keyed CW beacon for transmission tests at a suitable site. As a stand-alone unit, the modulator can also be used on any other LF transmitter we might desire to put to air.

A connector strip at the rear of the metal box provides for connection of *RF in* from the VFO, *SSB out* to the transmitter amplifier and *12 Volt supply.*

Integrated circuit packages used in this project were selected on the basis of them being on hand at the time and may not be readily available from local sources. However there is nothing critical about their selection and if anyone wishes to duplicate the circuitry, there are plenty of alternative packages. For example any general purpose op amp package such as the twin uA747 could be used for the speech amp and following balancing stages. As mentioned before, packages such as the NE602 or MC1460 could be used for the balanced modulator stages. For RF amp V4, a substitute op amp should have a high open circuit gain at 200 kHz. In the case of the digital packages, (the counter and the twin JK flip-flop), CMOS logic was chosen for operation on the 12V rail.

Performance

Peak power output level in the transmitter power amplifier can be achieved with a signal from the output of the modulator of around 6VPP. For this level, an audio level of around 6VPP is required at the input of amplifier N1A (figure 3) and the signal level from the microphone must be not less than 2 mVpp.

With careful adjustment of RV2, RV3 and RV4, the residual carrier level at the output of the transmitter can be set as low as 60 dB below maximum power output.

Optimum settings of these controls are slightly different for the upper or lower sideband. However, I imagine that if a band is approved, we would settle on a standard for which sideband is used and I don't expect there would be a need for regular on air changing between the sidebands.

I haven't any test figures for opposite sideband rejection. To measure this accurately, one needs a calibrated spectrum analyser which was not available for my tests.

Of course, there are no on air test results as these will depend on approval to transmit or approval of an LF amateur band.

Summary

A Single Sideband Modulator for the Low Frequency (LF) region has been described. The unit was constructed to operate in conjunction with the LF Transmitter previously documented by the writer and published in the February 2000 issue of *Amateur Radio.*

However as a stand-alone unit, it could well be used with any other LF transmitter.

The single sideband system uses the phasing system of balancing out the opposite sideband. The need for precision components in the audio phase shift network in this system is often emphasised as a problem for home constructors. However the writer found that by using the *polyphase network*, it seemed a lesser task than making operational the crystal ladder filter often used in the filter single sideband system.

A feature of the phasing system is that it does not need tuning or frequency dependent circuits in its generation. The only frequency dependent element in this unit is a low pass filter set to cut off higher order components of frequency above the LF band of operation..

References

1. Lloyd Butler VK5BR - *An Experimental Low Frequency (LF) band Transmitter — Amateur Radio,* Feb. 2000.2. Lloyd Butler VK5BR - The Ladder Filter Revived - Amateur Radio, March 1990.
3. *Radio Communication Handbook (RSGB),* Sixth Edition, Chapter 7 - HF Transmitters and Transceivers.
4. *ARRL Handbook for the Radio Amateur,* 1989 Edition, Chapter 18 - Voice Communications.

APPENDIX

Explanation of Phasing Method of SSB Generation with Vectors

(From RSGB Radio Communications Handbook)

For this explanation, reference is made to figure A1. Diagrams (a) show two carriers A and B of the same frequency and phase, one of which is modulated in a balanced modulator by an audio tone to produce contra-rotating sidebands A1 and A2, and the other modulated by a 90 degrees phase shifted version of the same audio tone. This produces sidebands B1 and B2 which have a 90 degree phase relationship with their A counterparts. The carrier vector is shown dotted since the carrier is absent from the output of the balanced modulators. Figure A1(b) shows the vector relationship if the carrier B is shifted in phase by 90 degrees and figure A1(c) shows the addition of these two signals. It is evident that sidebands A2 and B2 are in anti-phase and therefore cancel whereas A1 and B1 are in phase and additive. The result is that single sideboard is produced by this process.

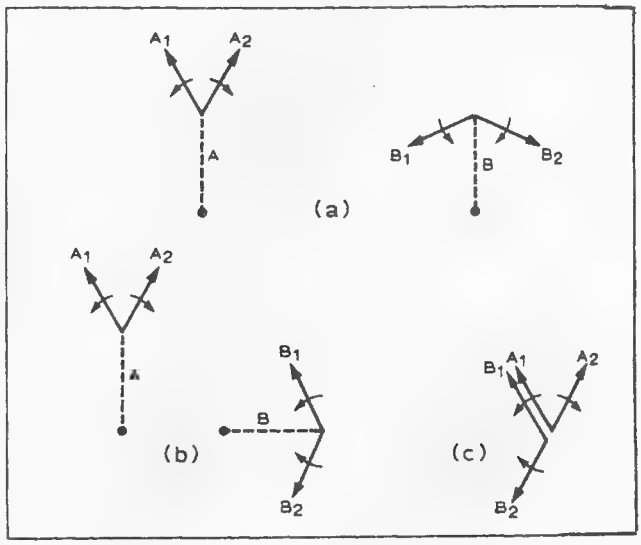


Figure A1: Phasing System Vectors
(From RSGB *Radio Communication Handbook*)

Be different!

Leave the mobile phone at home.

Take your handheld instead!

Correction

Amateur Radio September 2000

A Single Sideband Modulator for the LF Transmitter.

Page 14, Figure 4 - Speech Amplifier - Capacitor C7 is shown as 0.1 uF. Loaded into the following 4.7k.ohm potentiometer, cutting of low speech frequencies is a little severe. To rectify this, the value of C7 has been increased to 0.47uF.

73 Lloyd Butler VK5BR

Gil Sones VK3AUI
30 Moore Street, Box Hill South Vic 3128

Giant LF Loopstick

A loopstick for reception of LF signals in the 70 to 340 kHz range was described in QEX Mar/April 2000 by Richard Q. Marris G2BZQ. This covers both the European LF band and the US lowfer band as well as the NZ allocation. A loopstick is used in broadcast radios and is much more compact than a loop. For LF a somewhat larger core is desirable and hence the giant LF loopstick.

To obtain superior sensitivity, selectivity and directivity a 12 inch 1.125 inch diameter ferrite rod was used. Such a rod is not a regular catalog item. The rod was made out of six 12 inch long 0.375 inch diameter rods cemented in a circle. F14 or equivalent ferrite rods were used. Even 12 inch rods are hard to find and they were made by cementing shorter rods end to end with Super Glue or any similar cyanoacrylate adhesive. Locally 4 inch /100mm rods are available as well as rods 200 mm long. The rod ends should be cleaned and rubbed with fine abrasive paper to slightly roughen them prior to glueing. The fabrication of 12 inch rods is shown in Fig 2.

The 12 inch rods are then assembled into a bundle of six around a centre core as shown in Fig 3.. The centre core is a 12 inch long 0.375 inch diameter wood or plastic dowel. The assembly is held together for glueing with strong elastic bands. The rapid setting adhesive is then

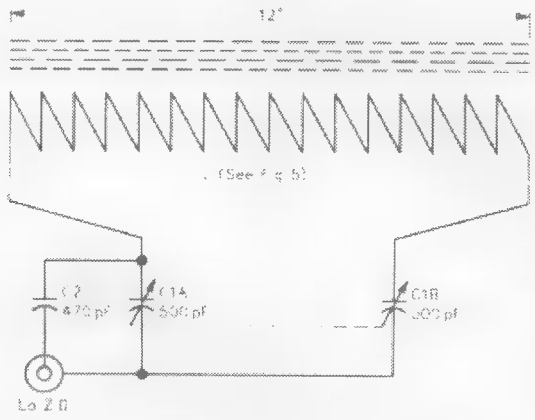


Fig 1. Giant Loopstick Schematic.

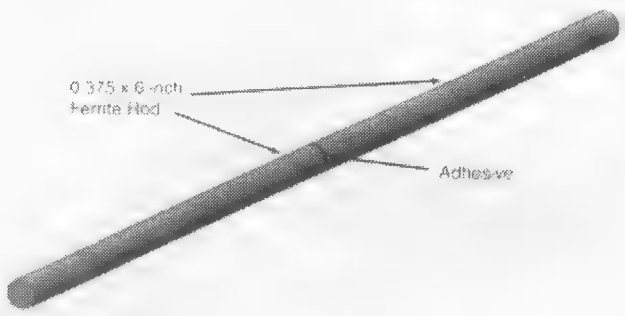


Fig 2. Fabrication of 12 inch Ferrite Rod from Two Shorter Rods.

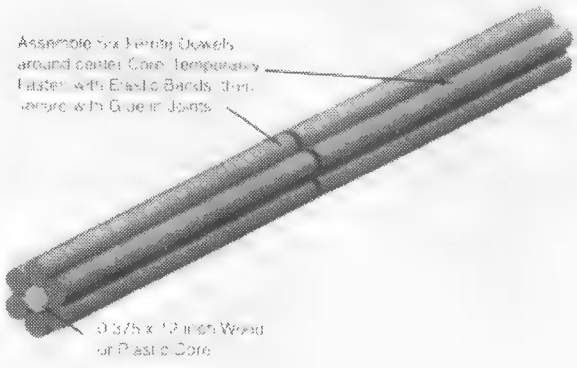


Fig 3. Fabrication of Giant Loopstick from Six 12 inch Ferrite Rods.

Fig 4. Cardboard Sleeve from box of kitchen wrap used as sleeve former for coil.

run into the valleys between the rods. Allow 24 hours for the glue to cure before cutting and removing the rubber bands. During the glueing process it is advisable to wear rubber gloves.

A 12 inch long 1.125 inch inside diameter thin wall cardboard tube is now required to be slid over the ferrite core as the coil former. Have a look at the tubes used in rolls of kitchen films or even a mailing tube. The tube is shown in Fig 4 and the coil is shown in Fig 5. The coil is an 11 inch long closewound winding of 24 AWG centered on the core.

The circuit of the giant loopstick is shown in Fig 1. The tuning capacitor is a twin gang 500 pf per section originally used in a broadcast radio. Capacitor C2 is a 470 pF silver mica capacitor which is used to match the loopstick to the 50 ohm output to the receiver.

The loopstick was mounted on a wooden base with the tuning and matching circuit mounted in a plastic box attached to the wooden base. The tuning range obtained was from 70 to 340 kHz. Slight differences can be expected due to component differences but should not cause significant problems.

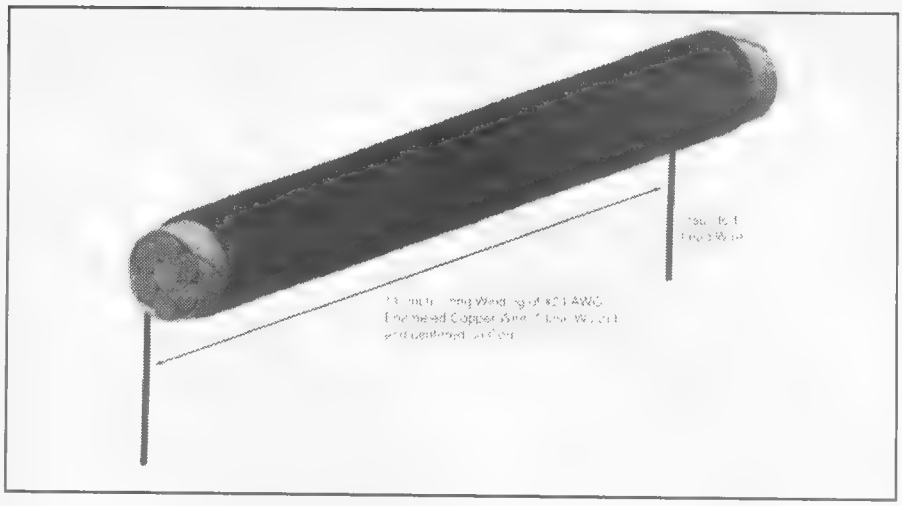


Fig 5. Coil Winding .

Giovannini D2T Antenna

An interesting wideband antenna was reviewed in CQ June 2000 by L. B. Cebik W4RNL. The antenna is the Giovannini D2T which offers a low SWR below 2:1 over a wide frequency range from the region of 160 metres through the two metre band. It uses a non inductive resistor to provide a termination and is one of an antenna class which includes the T2FD design marketed by B & W. Similar antenna types are used for a variety of commercial and military uses where wide coverage together with an acceptably low SWR are important considerations.

The antenna looks a bit like a ZL Special as it consists of two elements joined by a crossed transmission line. The elements are folded dipoles with an 820 ohm termination at the centre of one and a matching transformer at the centre of the other. The antenna is shown in Fig 6. together with the T2FD design marketed by B&W. Both use a termination and a matching transformer. The matching transformer is a wideband design which matches the 50 ohm feed to the antenna 800 ohms.

The Giovanni D2T is made out of wire of approximately 14 AWG. The boom is aluminium and the elements are supported by fibreglass spreaders. The termination resistor which must dissipate a significant amount of power is mounted in a fibreglass tube as weather protection.

At lower HF frequencies the gain decreases below 10 MHz. However gain is probably the wrong word as the antenna is small at these frequencies and losses are considerable. However it does radiate and if the signal is sufficient and the SWR does not upset the radio this may be acceptable.

Above 10 MHz the antenna efficiency improves and at higher HF frequencies some directivity is evident for the 12 and 10 metre bands.

While the antenna provides SWR performance into the VHF region it may not be an antenna of first choice for 6 or 2 metre band operation. At the upper end the pattern exhibits a number of lobes.

The antenna is made by Giovanni Elettromeccanica, Via Enrico Mattei 9, 50039 Vicchio (Florence) Italy. Giovanni's website is <http://www.antenna.it> .The price in the USA is in the US $ 500 to $ 600 region.

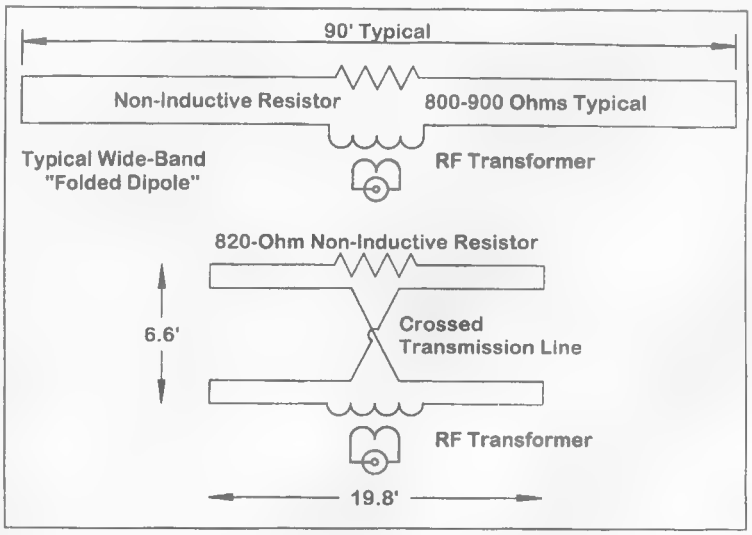


Fig 6.T2FD and Giovanni D2T Antennas.

A HF to LF Transmit Frequency Converter

Lloyd Butler VK5BR

Any mode (e.g. CW, AM, SSB, FSK) which is initiated in the HF transmitter or transceiver can be regenerated at LF (100 to 200 kHz) using this simple converter. The output at LF can be used to drive an LF Power Amplifier.

The February, 2000 issue of Amateur Radio (ref. 1) contained an article I had submitted on an LF transmitter. The transmitter was designed for CW operation but the power amplifier was operated in a linear mode and it was only a matter of replacing the VFO with some form of AM or sideband generator with an LF output to operate on speech.

The article was followed up with a further article (Amateur Radio September 2000 ref 2) on a Single Sideband Generator using the phasing technique. The design aimed at making a stand-alone unit because of the possibility of using the unit at a site away from the amateur station. However it was pointed out that a simpler arrangement might be achieved at the amateur station site by heterodyning down from the HF output of the local HF transceiver. This third article describes a circuit designed to do that conversion and provide sufficient LF output level to drive the original power amplifier.

The Converter circuit

The circuit diagram of the converter is shown in figure 1. The conversion takes place in V1 (type NE602). The V1 circuit is almost identical to that used in my Active Loop Converter (Amateur Radio July, 2000 - ref 3) except that the input and output frequencies are reversed. I used the same 4 MHz xtal as in the receive converter as I had another one spare. Most HF amateur transceivers tune up to 4 MHz on the 3.5 MHz band so that it is simply a matter of setting the transceiver frequency to 4 MHz minus the LF transmission frequency. (4 MHz plus LF transmission frequency could also be used if the transceiver is tuneable above the 4 MHz. - This would make easier setting of the required HF frequency. Of course there is nothing to prevent some other crystal frequency being used with appropriate setting of the transceiver output frequency.).

The overall circuit gain of V1 and V2 is arranged so that the HF input to V1 operates around 20 to 30 mVPP for peak signal level. This was chosen as it was anticipated that above these levels, steep increase in the level of intermodulation products could cause distortion in the audio signal when demodulated. This effect, relevant to the NE602, was discussed in one of my previous articles (A.R. Jan 1994, ref 4).

HF Transmitter Pick-up

There is no point in running the HF transmitter at high output level to generate a signal. I reduced the power on an FT101B used to around 1 watt by backing off drive to the PA. The output is loaded into a dummy load and paralleled off to an attenuation network R1-RV1-R2-R3. (Note the connection via the coaxial T connector in figure 1.). The precise amount of drive for a given HF transmitter power is set by RV1. Diodes D1 and D2 provide some protection to V1 in the event of excessive RF level.

LF Output

To attenuate mixing products above 200 kHz, the LF output from converter V1 is fed into a low pass network formed by L1-C9 and the feedback circuit of V2. The following LF Power Amplifier requires 6VPP at maximum swing and stage V2 raises the output from V1 to this level. The circuit is similar to that used at the output of SSB modulator (ref 2) but the gain has been raised from the original value of 10 to around 70 by changing the values of R5 and C8 to those shown. With this arrangement, the 6VPP is achieved with around 25mV of HF signal at V1 input. Maximum possible output level from V2 is 9VPP.

DC Power

The complete converter is powered from 12V DC and when operated in conjunction with the Power Amplifier (ref 1), the supply it is picked up from 12V in the Amplifier unit. A further 6V rail is derived with Zener diode ZR1 and resistor R7. This is used to power the NE602 converter, V1 and to set the operating point of amplifier V2 at half its12V operating supply. Load current at 12 volts is 15mA.

Components

There are no specialised components. L1 is a miniature choke available from electronics stores. The two I/Cs are mounted in 8 pin DIL sockets. The 4MHz crystal was a HC25 style but any crystal of suitable frequency could have been used. The precise frequency of the crystal can be adjusted by varying the values of C4 and C5. The input connectors, including the T, are BNC type but some other type could have been used. The small components (except R1) are mounted and interconnected on a piece of blank circuit board. To prevent stray coupling from the high level at the input to R1 from getting into the rest of the circuit, I found it necessary to remove R1 from the board and shield it and its connecting lead to the input connector. The complete unit is mounted in a 100mm x 60mm x 45mm aluminium box.

Adjustment, Operation, Performance

The only adjustment is the input level control RV1. For operation with the nominated power amplifier, RV1 is set for a maximum signal level of 6VPP at the output of the converter.

The converter has been tested in conjunction with a HF transceiver using

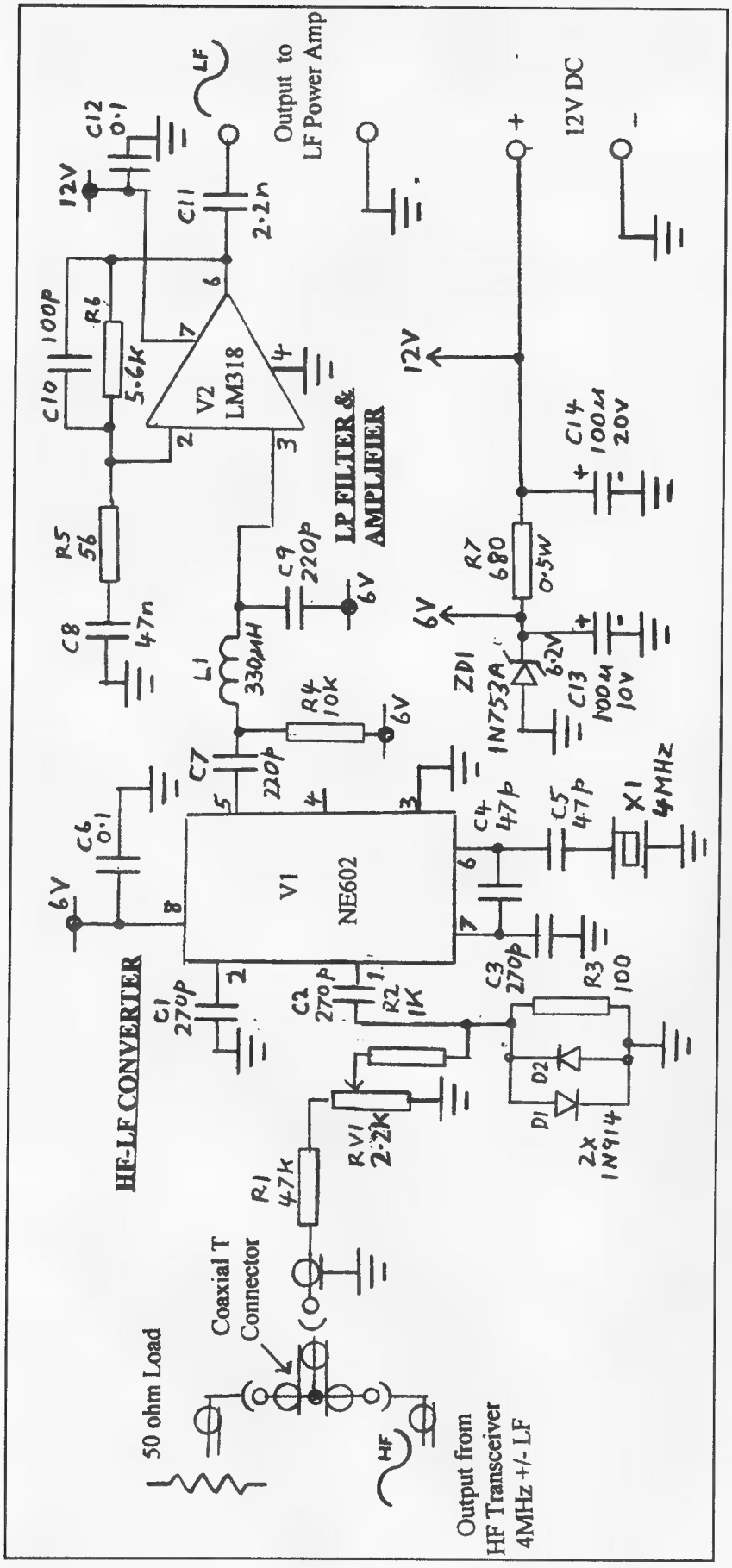


Figure 1: HF to LF transmit Converter

CW, AM, and SSB modes and with the LF Power Amplifier loaded into a dummy load. At the time of writing, negotiations by WIA for a new LF amateur band were still in hand. Hence, no air tests to date have been possible.

Performance Summary:

Low Frequency output range - 100 to 200 kHz

Input Frequency (with 4 MHz Crystal) - 4 MHz +/- LF

Maximum LF output level - 9VPP

Nominal working level at converter (NE602) input

for 6VPP LF output - 20-30VPP

Mode - any form at HF input (e.g. CW, AM, SSB, FSK)

Power rail - 12VDC

Power rail load - 15mA

Summary

A frequency converter has been described which can reproduce, at 100 to 200 kHz, any mode of transmission from the output of a HF transmitter or transceiver. Its output circuit was specifically designed to drive the power amplifier in the LF transmitter described in February 2000 AR. However it could be used to drive other LF power amplifier as required.

References

1. *An Experimental Low Frequency Band Transmitter* - Lloyd Butler VK5BR
   Amateur Radio, February 2000.
2. *A Single Sideband Modulator for the LF Transmitter* - Lloyd Butler VK5BR
   Amateur Radio, September 2000
3. *An Active Loop Converter for the LF Bands* - Lloyd Butler VK5BR
   Amateur Radio, July 2000.
4. *The Bandwidth Limiting LF Converter Simplified* - Lloyd Butler VK5BR
   Amateur Radio, January 1994.

Antenna Noise and Signal Cancelling at LF

Lloyd Butler VK5BR

By using the signals from two antennas, controlling their relative amplitudes and controlling the phase of one of them, unwanted signal or unwanted noise can be phased out. Circuitry is described which uses the signal from a wire antenna to provide selective cancelling against the signal output from an LF loop antenna.

Introduction

The fact that the phasing between a wanted signal and an unwanted signal can be different on different antennas is put to advantage. With this condition, the unwanted signal can be cancelled out by controlling amplitude and phase. The heart of the system is some form of phase control circuitry. I described methods for doing this at HF in AR Sept. 1992 (ref. 1) and AR Jan. 1993 (ref. 2). The second system made use of the 180 degree phase shift which was achieved when two lightly coupled tuned circuits were tuned from one side of resonance to the other by a ganged pair of variable capacitors. It is this system which is again used at LF.

The circuit described provides a phase and amplitude controlled auxiliary signal from a wire antenna. Whilst its output could be used to mix with some other antenna system, it was specifically aimed at mixing in with the signal from the loop antenna in the active loop converter described in AR Jul 2000 (ref. 3).

Circuit Detail

The circuit diagram is shown in figure 1. The auxiliary wire antenna is coupled into the phase control network L1-L2-L3-C1A-C1B via R10. The network is made up of two tuned circuits C1A-L1 and C1B-L2 coupled via inductor L3. The three inductors are miniature chokes obtainable from electronics stores. C1A and C1B with maximum capacities of 450pf are ganged. Using the component values shown, the circuit is tuneable over the range of 160 to 500 kHz. A phase control range of 180 degrees is achieved tuning from one side of resonance to the other with an amplitude variation not greater than 6db.

The phase control network is interfaced with amplifier V1A which is one half of an LM353 twin mosfet op. amp package. The circuit constants are set for a gain around 25. The other half, V1B, is connected as a phase inverter to provide the second half of the 360 degrees phase range. Switch S1 provides selection of one or the other ranges of 180 degrees.

The amplifiers operate from 12V DC picked up from the loop converter supply. Their operating points are set by 6V derived from R8 and R9.

The output from the auxiliary circuit is mixed in with the output from the loop converter interface amplifier at the NE602 mixer input, pin1. As there is a second input to the NE602 (pin2), I could have fed the auxiliary signal via this second pin. However, I would have had to disconnect the converter circuit board card, remove it from its mounting and modify the board. I found it easier to add circuitry around the loop gain control RV2, as shown in the top right hand corner of figure 1, so that both signals are fed to pin 1.

There is nothing specific about requirements for the auxiliary antenna. The normal radio shack antenna used for HF communications can be connected for this purpose.

Operation

A little bit of practice is needed to set up the system on a station tuned in.

First of all set the auxiliary antenna gain control RV1 to zero and loop gain control RV2 in the converter well advanced or at maximum. Adjust the loop tuning for resonance indicated by maximum signal.

Now set the loop gain control RV2 to zero and advance the auxiliary gain control RV1. Adjust C1 in the phasing circuit for resonance indicated by maximum signal.

Restore loop gain control RV2 to its previous position so that signals from both antenna are feeding the mixer. Assuming there is unwanted noise or signal, carefully 'fiddle' with the tuning of C1 either side of resonance and the setting of auxiliary gain RV1 to find a null in the unwanted noise or signal. If there is no success, reverse phase with switch S1 and try again.

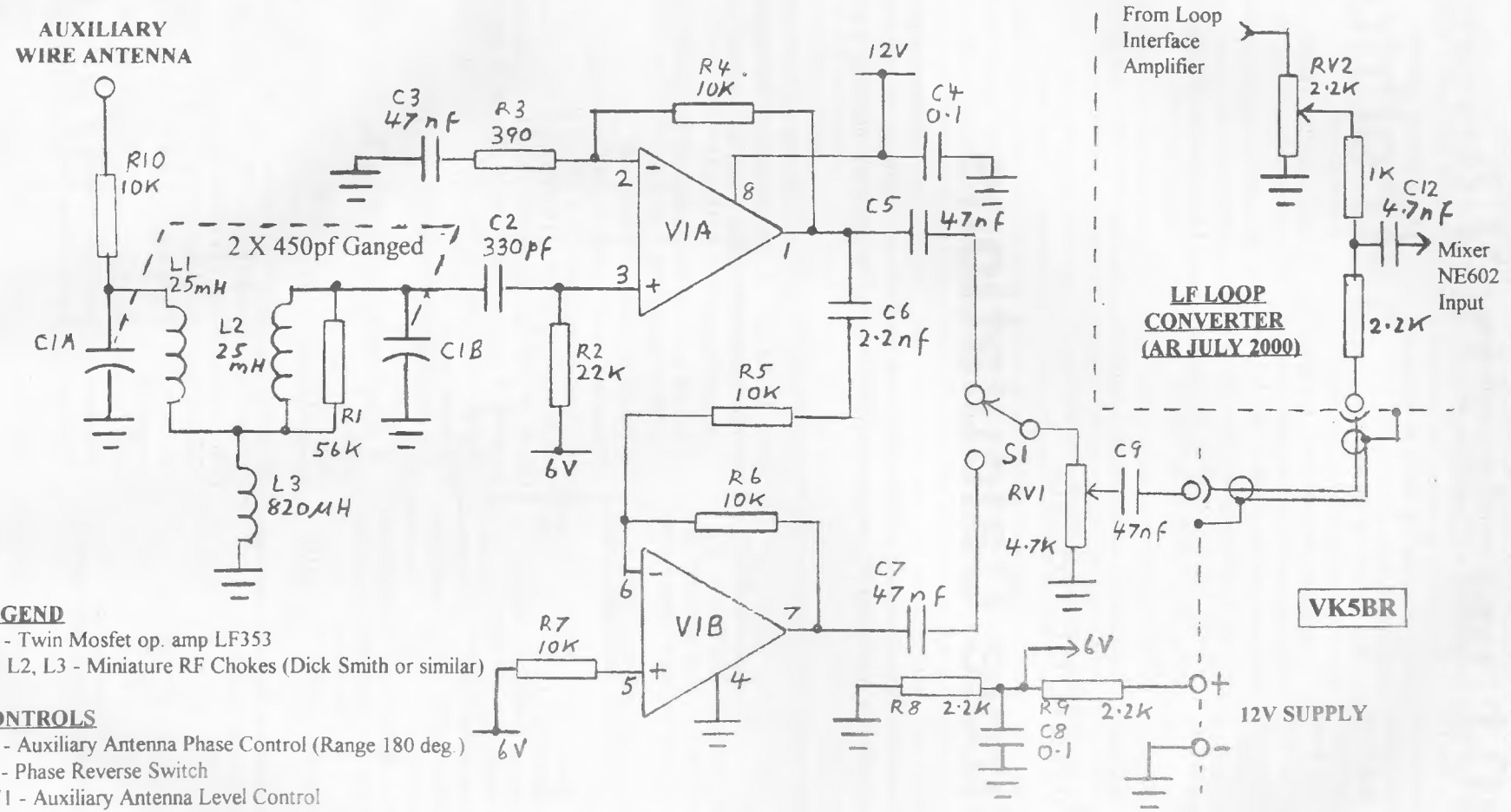
For the cancellation to work, the unwanted noise or signal from the auxiliary circuit must be at least equal in level to that from the loop circuit. If this is not the case, it might be necessary to reduce the loop level (RV2) to achieve this condition.

Performance

Whilst the main purpose in setting up the cancelling circuit was to phase out locally generated noise, it has also proved to be useful in separating signals. There are a multitude of aeronautical NDB signals to be heard above 200 kHz and many of these stations are on the same frequency or very close in frequency. Tune across the band and at many tuned positions more than one station ident. can be heard.

Assuming the signals are from different directions, one way to separate one station from another is to carefully set the loop null in the direction of the signal to be rejected. However, independent of the loop position, the cancelling circuit is also very effective in phasing out the unwanted signal. It is interesting to phase out one or the other of two signals so that each can be heard on its own, one at a time.

If there is no signal or noise to be cancelled, another interesting aspect of having two different types of antenna is that either can be selected to operate in its own right. If the signal from the loop seems better than that from the wire antenna , just set RV1 to shut off the auxiliary signal. If the signal from the wire antenna seems better, set RV2 to shut off the loop.



LEGEND

V1 - Twin Mosfet op. amp LF353

L1, L2, L3 - Miniature RF Chokes (Dick Smith or similar)

CONTROLS

C1 - Auxiliary Antenna Phase Control (Range 180 deg.)

S1 - Phase Reverse Switch

RV1 - Auxiliary Antenna Level Control

RV2 (in Loop Converter) - Loop Antenna Level Control

FIGURE 1

LF Noise Cancelling Circuit

Frequency Range - 160 to 500 kHz

Summary

The LF Noise & Signalling Cancelling circuit is a useful addition to the LF receiving system where localised noise is a problem. It is also useful to phase out an unwanted signal near the frequency of the signal being received.

As described, the circuit has been designed to operate in conjunction with the LF Active Loop Converter described in AR, July 2000. In the combined arrangement, the following is achieved:

The advantage of the loop with its properties of directivity and insensitivity to the high level electric component of localised noise.

The ability to raise the Q of the loop by feedback and limit its bandwidth.

The ability to phase out unwanted noise or signal by using an additional antenna pick-up.

The ability to select loop or wire antennas for best signal condition.

Using components shown in Figure 1, the phase control circuit works over the frequency range of 160 to 500 kHz. No attempt has been made to operate below 160 kHz but this might be achieved by using large values of inductance in the circuit.

References

1. *An Interference Cancelling System for your Receiver or Transceiver* -
   Lloyd Butler VK5BR - Amateur Radio, September 1992.
2. *More on Interference Cancelling and a New Circuit* -
   Lloyd Butler VK5BR - Amateur Radio, January 1993.
3. *An Active Loop Converter for the LF Bands*
   Lloyd Butler VK5BR - Amateur Radio, July 2000

A Low Frequency Beacon Transmitter

Richard Rogers, VK7RO

I have been listening to low frequencies for some years since Robert, VK7ZAL, obtained a scientific licence (AX2TAR) and constructed an experimental low frequency transmitter and asked for reports.

However, I was unable to hear the New Zealand amateurs until I used the low noise reception techniques described in Break-In by ZL2BBJ (1). The essential requirement is to use a small antenna isolated from the noisy 240V power.

Recent information published by the WIA (2) suggested that a low frequency band may be available soon. So it seemed to be time to try a few ideas for transmitter construction.

At low frequencies, only vertical polarization is useful, and the average back-yard vertical antenna will have a gain of about minus 30dB, so signals at a distance will be very weak.

To overcome this, Steve, VK2ZTO (3), has suggested the use of frequency shift keying and computer sound card software to display the received signal visually. This allows the reception of signals well below audibility, the disadvantage being that the signalling is very slow. His program, VFSKCW, use Morse code with the "dashes" of equal length to the dots, but at a higher frequency.

I have used this idea to encode an ident in VFSK Morse as well as in normal Morse for a low frequency beacon transmitter. The beacon cycle consists of my call sent three times in normal Morse at 10wpm and once in VFSK Morse with 5 second "dots" and "dashes". This cycle take two or three minutes.

Some amateurs in the UK are using switch mode mosfet transmitters (4) and this seemed a good idea to try, especially as I had not used power mosfets before and excellent efficiency should be possible.

My transmitter circuit is shown in figure 1.

Power mosfets make very efficient switches and are commonly used in switch mode power supplies. They work best when driven by a very low impedance source to minimise feedback and switching times. Rockby Electronics were offering surplus BUZ350, N-type mosfets (200V, 22A, 0.12ohms) at a good price, so I bought 20.

I chose to use the TelCom TC4427, a high power CMOS, dual, non-inverting driver capable of 1.5 amp peak output, ideal for driving the 1300pF input capacitance of the mosfets. I bought mine from Farnell (part number 295-036).

To generate the LF drive I use a PIC16F84 micro-controller. This is a complete micro-computer comprising processor, memory and input/output ports all in an 18 pin chip. It has the great advantage that it is re-programmable, allowing program development by a somewhat "trial and error" method. Ideal for me!

The program has to divide the PIC's crystal clock down to generate the LF signal while at the same time generating the ident signal. By using a high crystal frequency it is possible to generate the drive signals with a time delay between mosfet on times.

The PIC I used was only rated to operate with a 4MHz crystal, but it ran reliably at 19MHz (the highest fundamental crystal I had), so I am happy using it with a 10.245MHz crystal to generate a 183KHz output. PICs are also available guaranteed to run at 10MHz and the PIC16F84A will run at 20MHz.

I use capacitive coupling between the PIC and the driver to (hopefully) avoid destroying the mosfets if I make an error in my programming and leave an output high. The diodes keep the 4427 drive signal between +4.3 and -.7 volt.

The BUZ350s are subject to damage by static electricity. To avoid this, I soldered the 56k resistors between the gate and source of the mosfets as soon as I took them from their conductive packaging. With these resistors permanently in place, there is little chance of damage during further handling.

The leads between the driver and the mosfets should be short, especially the earth connection.

To reduce the high peak voltages when the mosfets are switched off, 4.7nF polypropylene capacitors are connected from each drain to earth. (Farnell 659-745)

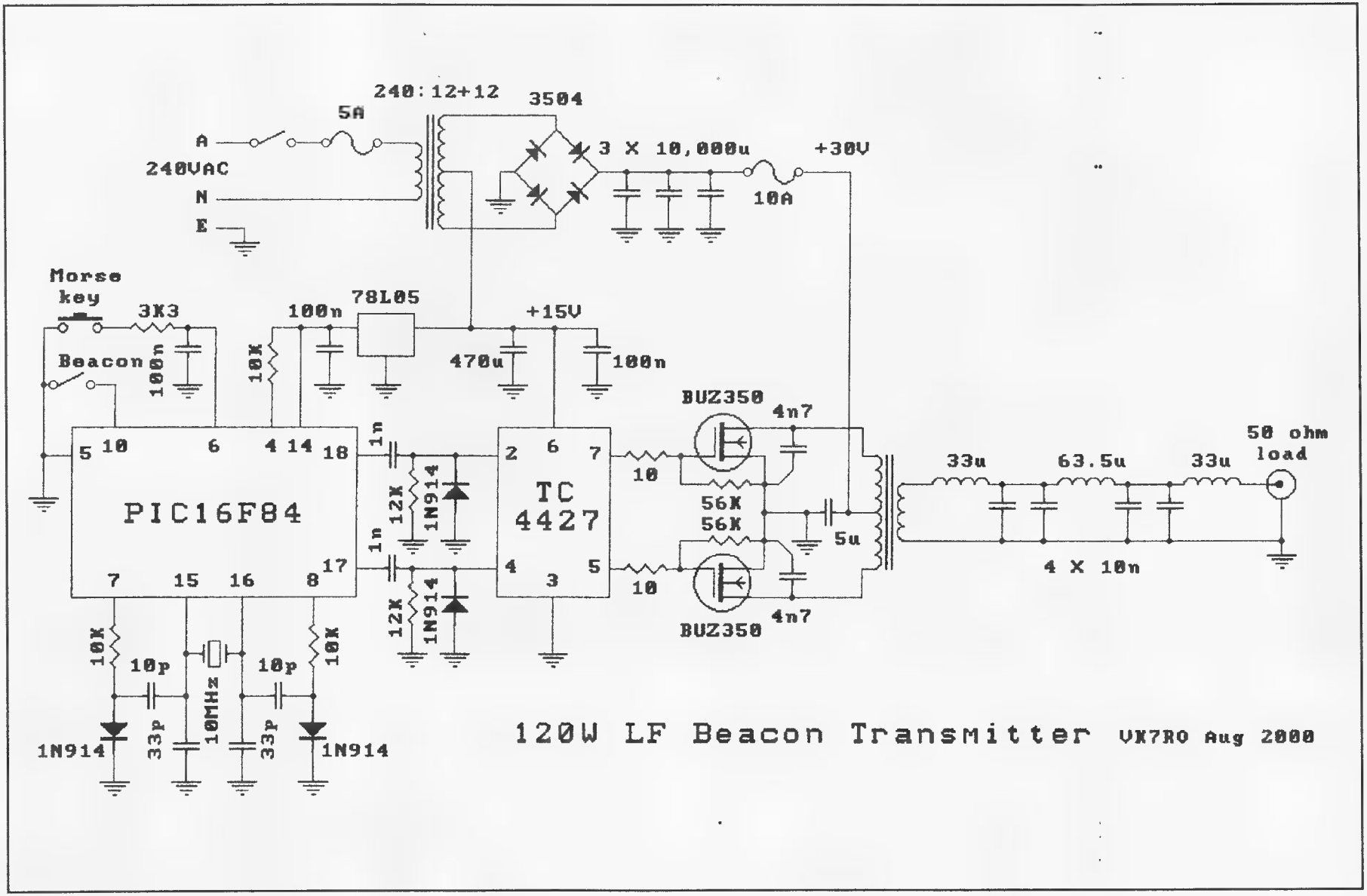
A number of different output transformer cores were tried, but I finally stacked two 35mm ferrite toroids from Jaycar (LO-1238). The primary is 5 turns of 26 X .3mm PVC insulated twin flex connected as a bifilar winding to reduce ringing. The secondary is 17 turns of 24 X 0.2mm.

The output low pass filter was made large enough to to handle higher powers in future. I used 1.6mm wire and 1600V polypropylene capacitors (Farnell 659-770). The filter coils are wound on 49mm formers. The 33uH coils have 31 turns and the 63.5uH coil has 54 turns. They are mounted mutually at right angles.

Keyclicks are minimised by ramping the drive duty cycle up and down in software. This proved to be better than using a keying transistor and capacitors.

The power supply used a 12V + 12V transformer which was on hand and the bridge rectifier gave a loaded output of 30 volt. 15 volt is available from the transformer centre tap for the driver chip and is dropped to 5 volt for the PIC with a 78L05.

The transmitter is very efficient. With 120 watt output the current drain with the 30 volt supply is 4.2 amp. Most loss seems to occur in the bridge rectifier. It needed a much bigger heatsink than the output mosfets!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+15V
Beacon
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100n
BUZ350
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50 ohm load
33u
63.5u
33u
PIC16F84
TC 4427
1n
12K
1N914
10
56K
5u
4 X 10n
10p
10MHz
33p
1N914
120W LF Beacon Transmitter VK7RO Aug 2000

Figure 1

The frequency shift is accomplished by using two of the PIC outputs to switch additional capacitors on its oscillator crystal. The frequency shift at 183KHz is 2Hz up for dashes and 2Hz down for dots!

Figure 2 shows the display from the program Spectrogram (5) reading the FSK signal with the transmitter running into a dummy load. There was no antenna on the receiver and the signal was only just audible. The fuzzy signal on the left is the normal Morse ident, where it is possible to see the sidebands due to the keying. The main part of the display shows my callsign in FSK Morse. Note that it starts and finishes with a space frequency between the dot and dash frequencies and there are space frequency marks between each Morse coded character. The computers colour display has more information than can be seen in black and white and signals well below the noise are readable.

I initially found Spectrogram tricky to set up. Figure 3 shows the set-up used to generate figure 2.

Copies of the program are probably best distributed as an e-mail attachment. Please contact me at vk7ro@netspace.net.au.

References:

1. Break-In May 1997 p22
2. WIA IARU paper at http://www.cck.net.au/iaru/papers/wia_lf_band_propossal.pdf
3. VK2ZTO at http://www.qsl.net/vk2zto/
4. G0MRF at http://www.g0mrf.freeserve.co.uk/ and G3YXM at http://www.picks.f9.co.uk/
5. Spectrogram at http://www.mnsinc.com/rshorne/gramdl.html

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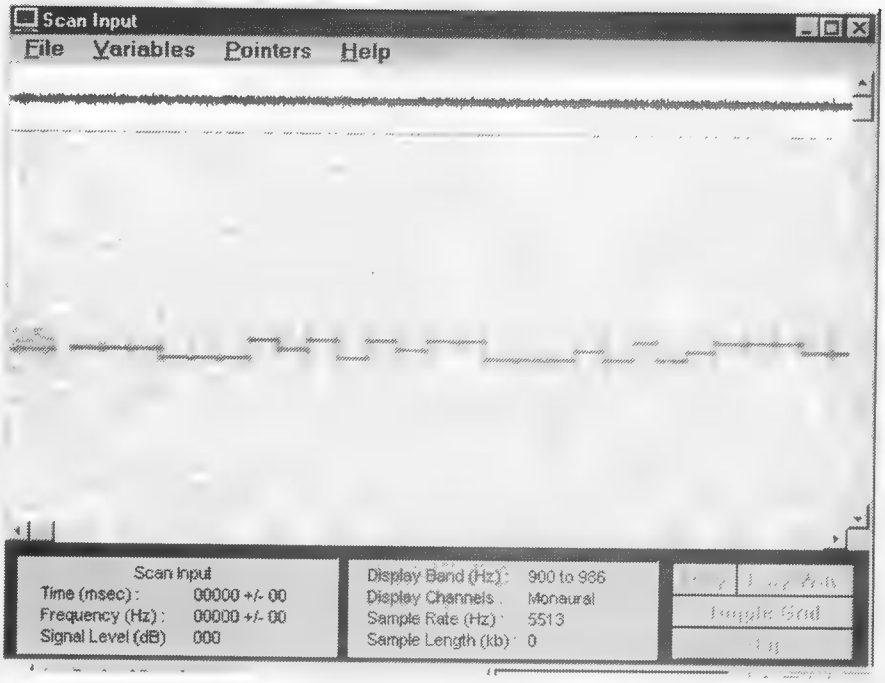

Figure 2

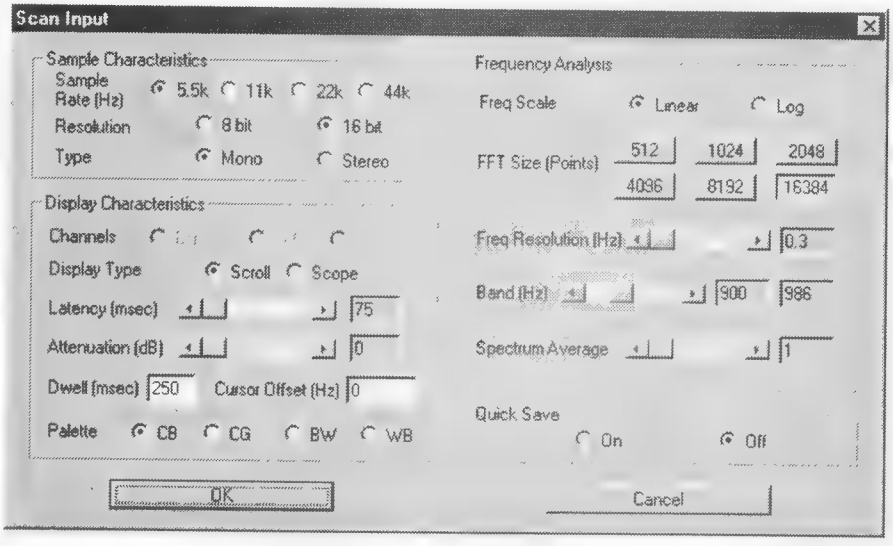

Figure 3

Be different!

Leave the mobile phone at home.

Take your handheld instead!

Correction

Amateur Radio September 2000

A Single Sideband Modulator for the LF Transmitter.

Page 14, Figure 4 - Speech Amplifier - Capacitor C7 is shown as 0.1 uF. Loaded into the following 4.7k.ohm potentiometer, cutting of low speech frequencies is a little severe. To rectify this, the value of C7 has been increased to 0.47uF.

73 Lloyd Butler VK5BR

Noise Blanking for the High Q LF Loop Antenna

Lloyd Butler VK5BR
18 Ottawa Avenue
Panorama SA 5041

A high Q tuned loop has many desirable features for LF reception including the reduction of localised noise. However the high Q prevents operation of the usual receiver noise blanker. The article describes how noise blanking can be achieved by using an auxiliary antenna in conjunction with the loop.

The advantages of using the tuned loop antenna for LF reception have been described in previous articles. The signal level induced into the loop is quite low and to ensure that this level is well above the inherent noise level of the following interface amplifier, it is desirable to use a loop which has high Q to achieve a high voltage multiplication within the loop tuned circuit. There are also a number of other advantages in raising the Q such as improving rejection of strong adjacent signals, which might cause cross modulation in the following mixer. However, this high Q inhibits operation of the normal noise blanker installed in most receivers. Noise blankers work on impulse type noise and the aim of the system described is to provide a means to blank out this type of noise whilst still taking advantage of the feature of high Q within the loop.

In previous articles, I described a loop converter (Reference 1) and a noise cancelling unit (Reference 2). These operated from an auxiliary antenna to provide a cancelling signal, which was mixed with the output from the loop antenna. In the following text I describe a further blanking unit, which is fed from the same auxiliary antenna and the same noise cancelling unit, but in this case the latter operates as a tuning and gain controlled interface unit.

The System

Figure 1 shows how the system is connected up. The auxiliary antenna is connected to the noise cancelling unit, which controls phase and amplitude for adjusting noise cancellation. The output of this unit is fed via a switch in the blanking unit and, with the switch selected for noise cancelling, the output is fed to the loop converter for mixing with the loop signal. For this switch connection, the system operates as described in Reference 2.

With the switch selected for noise blanking, the noise cancelling unit output is fed into the blanking detector. In this operation, the phase control is

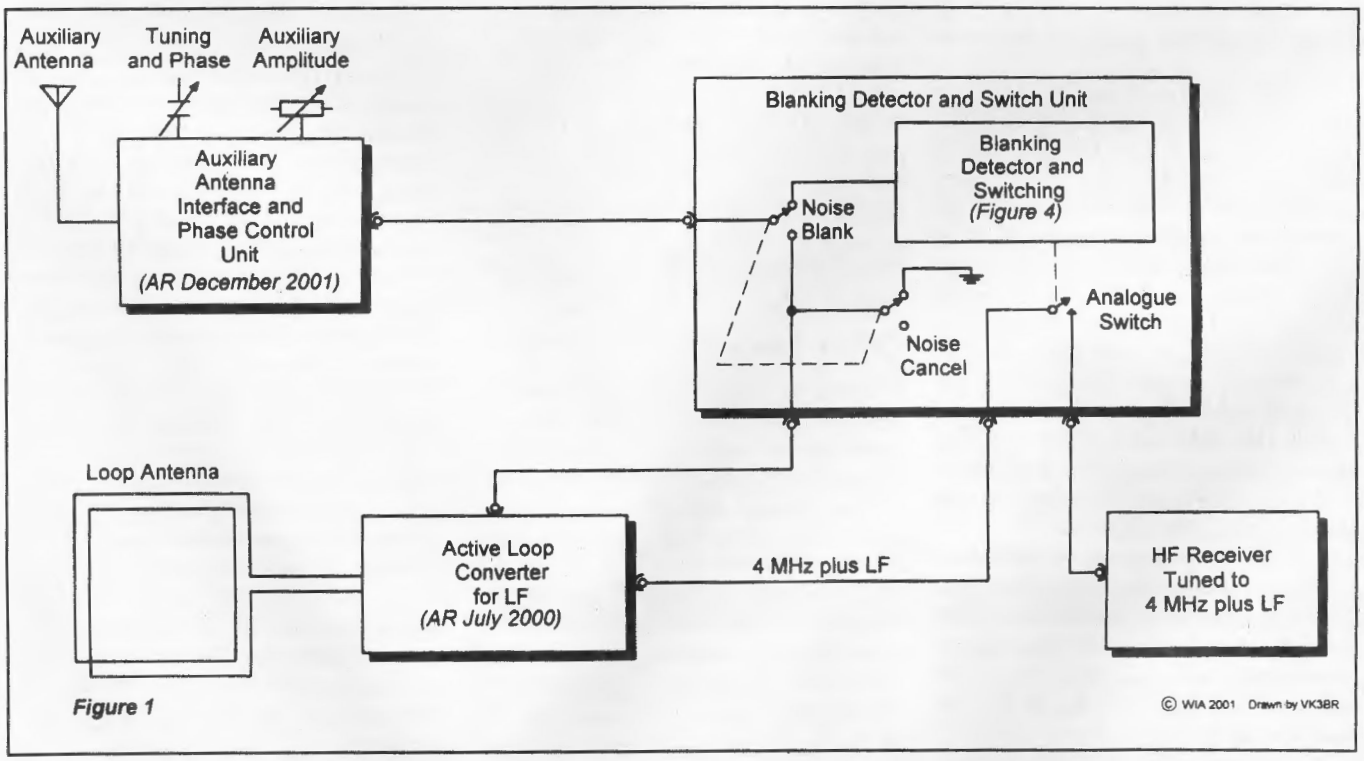

Figure 1. Active loop converter set-up with noise cancelling and noise blanking arrangement

simply a tuning control and the amplitude control sets the level into the blanking detector. When triggered, the blanking detector operates a CMOS bilateral analogue switch, which opens the 4 MHz loop converter output to the host HF receiver for a defined preset period.

The noise cancelling and noise blanking units are in separate metal boxes to the loop converter and the three are interconnected via BNC connector ended cords. The arrangement is how the experimental system evolved. I initially built the LF Converter with regeneration for Q control. I later thought I would try noise cancelling and later again the blanking system.

Impulse Noise and Blanking

I t is interesting to observe with a CRO what happens across a tuned circuit when it is energised by a short impulse. The tuned circuit is triggered into oscillation and a damped wave train is generated with each cycle decreasing in amplitude to that of the previous one. The higher the Q of the tuned circuit, the longer it takes to dissipate the energy and the longer it takes for the amplitude to fall to a given low level.

A formula derived from information in the Admiralty Handbook gives N as follows:

$$N=1+0.73Q$$

where N = No of cycles for amplitude to fall to 10% of initial value, and Q = Circuit Q

A sample frequency of 200 kHz is the lowest frequency for aeronautical non-directional beacons and is close to the New Zealand amateur band of 165 to 190 kHz. The period of one cycle at 200 kHz is five microseconds. Selecting this frequency and using the above formula, Fig 2 is evolved plotting time for the damped wave train to fall to 10% of its initial value verses circuit Q.

Take a good typical loop, which has a Q of 200. It can be seen from the curve that for this loop, it will take more than 735 microseconds for a triggered wave to fall to a negligible value. If the effect of the impulse is to be eliminated, the received signal will have to be switched off (or blanked out) on the first cycle and remain off for a period not less than 735 microseconds.

Now let's turn to the question of how the start of blanking is initiated and how the impulse is selectively detected. The blanking system normally relies on the fact that the impulse is of higher amplitude than the signal and is of very short duration so that the blanking is triggered by this short pulse. If there is a tuned circuit in the triggering path and the Q is low, triggering occurs on the first cycle of the damped wave train generated and the second and subsequent cycles fall away rapidly in amplitude so that they don't confuse the triggering circuit.

However, if the Q is high, the change in amplitude from cycle to cycle is very small as the decay of amplitude with time is stretched. Detecting this to operate the blanking trigger produces a stretched version of the original impulse, which is unsuitable for edge triggering of the blanking switch. So, to get over this problem with the high Q loop, we feed the blanking trigger from an auxiliary wire antenna via low Q tuning. We could also use an untuned noise pick-up but some form of selective tuning or bandpass filter is needed, at least in the City, to stop false triggering of the blanking circuit by strong local broadcast stations and aeronautical beacons.

As it turns out, the tuning system in the unit already built for noise cancelling has quite low Q and I was able to put the unit to use, without modification, as the auxiliary antenna interface for the blanking unit.

An interesting point is that this problem of the noise blanking system not working with the high Q loop is a characteristic of the low frequency band. As already discussed, for a Q of 200 at 200 kHz, the decay period of the impulse triggered damped wave falls to 10% of its initial value in 735 microseconds. However, for a Q of 200 at 2 MHz, the decay period is only 73.5 microseconds and is possibly short enough to work the normal blanking circuit.

To demonstrate this theory, I tested another loop antenna, which I had made for 1.8 MHz, on two different HF transceivers with blanking fitted. The loop has a Q of around 100 and, based on the above calculations, would have a decay period to 10% in 41 microseconds. The blanking worked quite successfully on impulse noise with impulse repetition frequencies of 50 and 100 Hz. Operation failed for higher repetition frequencies, but the blanking circuits were probably only designed to cope with power line interference at the lower frequencies. Using the same transceivers converted up from 200 kHz with my LF loop set to a similar Q, there was no way in which blanking would work.

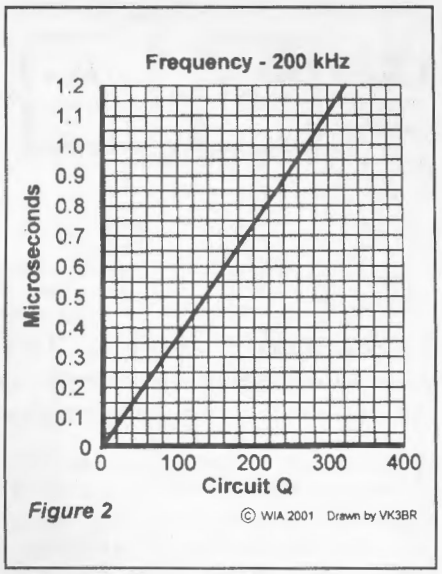

Figure 2. Tuned circuit triggered by impulse. A plot of the decay time for damped waveform amplitude to fall to 10% of its initial value versus circuit Q.

The Blanking Unit

Fig 3 is a block diagram of the blanking unit. Circuit detail is shown in Fig 4 and operation is as follows:

Noise signal from the auxiliary antenna interface unit is amplified by the two stage amplifier N1, a twin JFET operational amplifier package type LF353. The output of N1 is coupled to Schmitt trigger N2 via full wave rectifier circuit L1, D1, D2. The idea of the full wave circuit is to ensure that the leading edge of the first half-cycle of the impulse initiated wave train triggers N2 independently of whether the first half is positive or negative. N2 (74LS14) is a TTL type of trigger requiring a five volt rail and this is derived from the zener diode circuit ZD1, R13. The five volts is also used to set the operating points of amplifiers N1. I could have used a CMOS type trigger here with the 12 V rail, but I didn't have one and I did have the 74LS14 on the shelf. There are six individual Schmitt trigger gates in the N2 package and, of course, five are spare.

The rectified output of D1-D2

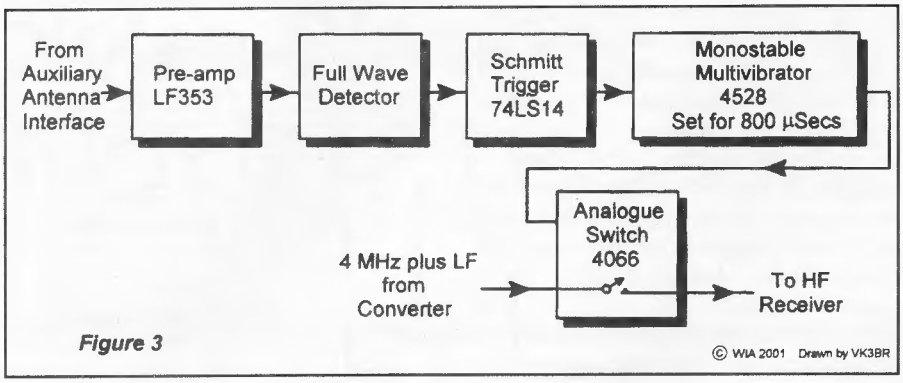

Figure 3. Blanking unit block diagram.

produces negative going pulses and N2 bias is set by trimpot RV1 so that N2 is triggered on by the negative going signal. I found it operated nicely at 1.8 V of bias.

When triggered, N2 produces a 5 V step which is differentiated by C5, R8-R9 and the spike flips the mono-stable multi-vibrator N3 (type 4528) to an 'on' state where it remains for a period determined by the values of R10 and C8. Because the output of N2 is only 5 V, the setting of reference voltage at pin four of N3 is fairly critical and this reference is set by the ratio of the values of R8 and R9.

Of course, the 'on' time of the multi-vibrator sets the blanking period and I experimented with this quite a bit. For very high loop Q, the blanking period can be advanced to around 800 microseconds. Advancing beyond this deteriorates the tonal quality of the detected audio signal as heard in the receiver. Referring to the 10% level curve of Fig 2, this equates to a Q of 220. In the loop converter used, I can apply regeneration and increase the effective Q to quite a high value. In practice, using 800 microseconds, I found that I could advance the regeneration control somewhat and achieve blanking on what would appear to be much higher values of Q. An explanation of this might be that most of the noise power is concentrated in the earlier part of the damped wave train and that is the most effective part to cut out by blanking.

The blanking period is easily altered by changing the value of C8. A blanking period of up to 800 microseconds (C8 = 10 nf) can be used for impulse repetition frequencies below 200 Hz such as the usual 50 and 100 Hz power line noise. Logically, the blanking period must be less than the impulse repetition period and must be reduced for higher impulse repetition frequencies. For impulse repetition frequencies up to 1000 Hz, a blanking period of 200 microseconds (C8 = 2.2 nf) can be used with the maximum loop Q then a little lower. As a compromise, I settled on 400 microseconds with C8 = 4.7 nF

Whilst most repetitive impulse interference in Australia probably initiates from the 50 Hz power mains, I mentioned higher repetition frequencies in the light of 600 Hz interference being reported in New Zealand due to DC to AC conversion in their power distribution system.

Switching out or blanking of the received RF signal is done by CMOS bilateral analogue switch package N4, type 4066 which contains four individual switch units. One is operated by the inverted (Q bar) output of N3. The normal condition is that this output is high and the switch in series with the RF circuit is closed. During blanking, the output of N3 goes low and the RF circuit is opened.

To help in reducing stray coupling across the opened series switch, two of the other switches are connected in parallel, one at the input to the series switch and one at its output. These are driven from the non-inverting (Q) output of N3 so that they are normally open when the series switch is closed, and closed when the series switch is open. The switches have a finite closed resistance of around 50 - 100 ohms and hence, as shunt units, they are not as effective as the series opening switch. However, as they are in the package, they might as well be used to provide a little extra attenuation during the blanking period.

The load current for the system from a 12 volt DC supply is as follows:

LF Converter	12.5 mA
Noise Cancelling Unit	6 mA
Noise Blanking unit	37 mA

The higher current in the Noise Blanking Unit is mainly due to the 5 V Zener diode regulator. Of course, this current could be reduced considerably by replacing the Zener with a small 5 V series regulator,

Operation of the System

As this article is meant to concentrate on the noise blanking section of the system, I don't intend to discuss in much detail the operation of the converter or the noise cancelling section of the system. These were previously described more fully in References 1 and 2.

In attempting to use either noise blanking or noise cancelling, it is important to check whether the noise to be reduced is also being received on the auxiliary antenna, otherwise neither system will work. To do this, the gain control for the loop is turned right down; the noise cancelling/noise blanking switch is selected to cancelling and the gain control in the noise cancelling unit is advanced. The tuning (cum phase control) in the noise cancelling unit is then peaked for maximum signal. After this is done, the loop gain control is restored to its maximum setting.

For noise cancelling, the phase switch, phase control and gain control in the noise cancelling unit are adjusted for minimum noise as described in Reference 2.

For noise blanking on impulse type noise, the gain control in the noise cancelling unit is turned right down and the noise cancelling/noise blanking switch is set to blanking. The gain control in the noise cancelling unit now becomes the blanking threshold control and is slowly advanced until the noise is reduced or ceases. Just past this point is likely to be the best setting; advancing too far might increase noise, or even blank the received signal right out by continuous triggering of the blanking switch.

One characteristic of the system might worry the operator when the loop gain control is turned right down with the blanking circuit still being triggered. With the signal removed, the AGC in the host receiver raises the receiver sensitivity to its most sensitive state and some noise pick-up from the blanking

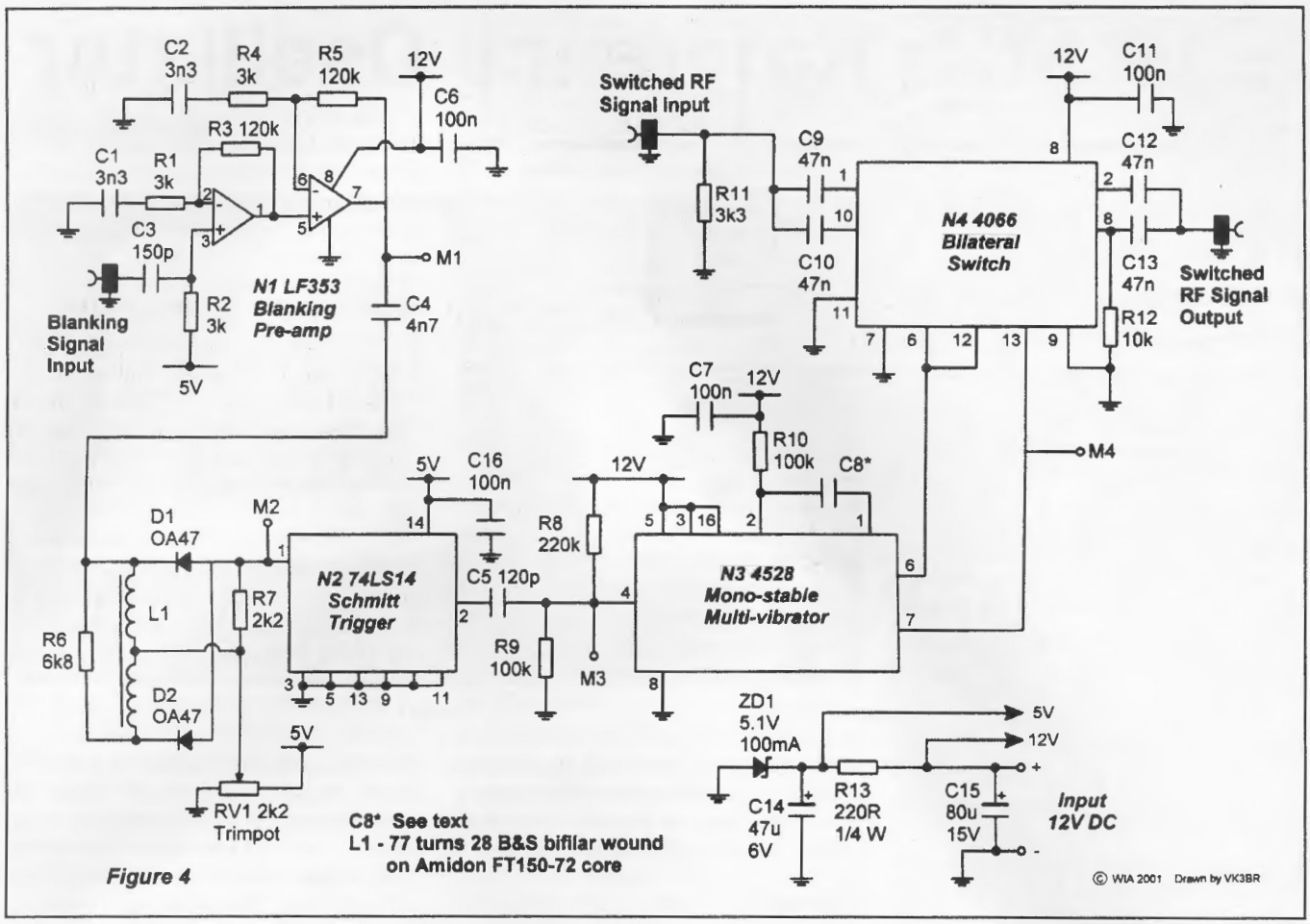

Figure 4. Blanking unit circuit diagram.

switching is apparent. This is well below the normal signal level and is essentially suppressed by the AGC when the loop gain control is advanced.

Testing the noise blanking system during experimentation can be a challenge if there is no impulse noise being received to make the tests. I found the easiest way to generate some noise for testing was to feed a square wave generator into a third antenna wire on the site and select a square wave frequency equal to the required impulse repetition frequency (say 100 Hz to simulate noise from power mains). To observe the waveforms in the blanking system with a CRO, simply synchronise the CRO time-base to the square wave.

In Conclusion

The high Q loop antenna has many advantages for use at LF frequencies, but the high Q can prevent the usual type of noise blanker from operating in the receiver. The article shows how noise blanking can still be achieved by using an auxiliary antenna with low Q tuning to feed the blanking circuit.

A blanking unit is described which is combined with a loop operated LF-to-HF frequency converter and a noise cancelling unit, both previously described in *Amateur Radio* magazine.

The combined system gives a choice of different ways to reduce noise interference and improve the general signal to noise ratio. Which way works best can depend on the nature of the noise. The various options include the following:

- Choice of loop antenna or long wire on its own, whichever works best.
- Use of the loop to make use of its directional properties and its insensitivity to localised electric field noise.
- Means to increase the Q of the loop antenna above its natural Q to limit the bandwidth of broadband noise and further restrict strong adjacent unwanted signal from causing intermodulation interference within the mixer stage.
- Use of the loop in conjunction with the auxiliary wire antenna to phase out unwanted noise or an unwanted other signal coming from a different direction.
- Use of the wire antenna as a noise reference to blank out impulse type noise, which might cause interference in the loop antenna.

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1. *An Active Loop Converter for the LF Bands* - Lloyd Butler VK5BR. Amateur Radio, July 2000
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The state of the art on Long Wave

John Adcock VK3ACA

This is a brief report on some things that have been happening in this region on LF (Low Frequency) or Long wave since my last article on the subject in AR, "The Day we Crossed the Tasman on Long Wave" Ref. 1. In this article reference is made to recent use of D.S.P. (digital signal processing) using a computer for weak signal detection. The author also acknowledges advice given by Bob ZL2CA, Richard VK7RO and some information from "Break-in".

Advantages and disadvantages of communicating on LF have been discussed to some length in previous articles and these will not be discussed here.

This article is not very detailed and the LF field is changing daily so my apologies if there are inaccuracies in the article!

The World scene briefly

In America an "unlicensed" band (CB band) has been used by amateurs since the start of CB. The unlicensed band, 160 to 190 kHz was intended for local, in house communications or control systems and not for long distance communications by amateurs. This facility allowed a maximum 1 watt input to an antenna no longer than 15 metres. Antennas of this type with typically less than 0.1% efficiency do not provide very much power. Never the less, American amateurs achieved some success with this mode especially using weak signal receiving techniques.

Prior to amateurs any where in the world being allowed to use a regulation defined low frequency band amateur band some amateurs obtained "Experimental licenses" (later known as a "scientific license"). In this country these are expensive and rather limiting.

Around 1990 New Zealand amateurs were given the use of the band 165 to 190 kHz and Papua were given the 160 to 190 kHz band at the same time. In New Zealand amateurs are allowed 5 watts EIRP (approx. 1.5 watts actual radiated power from a short mono pole). This frequency range was based on the American unlicensed allocation. The band was issued on a non-interference to other services basis.

The main objections by licensing authorities in most countries to increasing amateur capability in the 160 to 190 kHz region are: -

1. That it is likely to cause interference to pilot carriers used on power lines used by power companies.
2. That the allocation is inside the Long Wave broadcast band in region one. Region 1 includes Asiatic Russia and Europe and Africa. (This objection applies more in America than here.)

In Australia the authorities have taken the view that they will consider any proposal which may be agreed to by the ITU. Such a proposal may be put at the next World Administrative Radio Conference.

Amateurs in UK were issued with a 73 kHz band (71.6 to 74.4 kHz) in 1996. In 1998 this was replaced with the more generally issued 135.7 to 137.8 kHz band in some European countries. This latter band has been allowed in a number of European countries which include UK, Germany, Portugal, Ireland, France, Switzerland, Italy, Luxembourg, Austria, Czech Republic, Slovak Republic, Belgium, Spain, Denmark, Holland, Sweden, Romania, Venezuela and several former Soviet states. The European band is just below the "region one Long wave broadcast band". Recently Argentina was allocated a band near the European band. The 73 kHz band is still being used but it is intended to be phased out.

There is a lot of negotiating going on in many countries for an LF band particularly in US but to date the Americans do not have an official low frequency amateur band.

VK and ZL activity using standard techniques

Activity in Australia has been rather slow. There are a few amateurs in Australia holding "Scientific Licenses". At the moment this does not include the author, I held such a license 10 years ago and have now let it lapse. Robert Milne VK7ZAL with the call sign AX2TAR appears to be the only one who is using his license. He has made transmissions using Morse CW and SSB but because of his limited license status he has to generate morse with the assistance of VK7FB. So far Robert has had 2 way communications with ZL1WB. There are several VK listeners who send reports but as far as I know, Richard VK7RO and myself, VK3ACA, are the only Australian amateurs who have weak signal DSP receiving capability on LF. Steve VK2ZOT and some other VK2s sometimes send in reports.

In New Zealand a group of interested amateurs run a net on Thursday evening in which Morse CW is the mode used in the LF transmissions. The net, known as "the low frequency group", starts on 80 metres at 0830z, 8.30 pm. NZ time on 3.670 MHz SSB. This net is open to any interested VK amateurs as well as ZL. The group of NZ amateurs arrange LF transmissions on 181.4 kHz, which start at 0900z, each transmission runs for 2 minutes. There are usually 4 to 6 participants and at the end of the approximately 10 minute period, reports are exchanged back on 80 metres. Arrangements are then made for a second test run starting at 1000Z and the same procedure of reports is repeated. The net concludes about 1030Z. These

times are put back 1 hour for daylight savings i.e.. start time of net, 0730Z.

At my QTH the results of this have not been very good so far. ZL1WB who has an enormous antenna can usually be heard here and should be good copy in a quiet location. Other ZLs are sometimes detectable here using DSP. But of course, this being designed for very slow morse code only draws a single line for ordinary morse and the morse characters are not visible.

Eighty metres itself is not all that good and quite often I can only copy one or two of the people in the net. Now summer season has started the 80 metre net is almost impossible, the net operates at the same NZ time, and with daylight savings it starts well before sunset.

Receivers and Antennas

A note on receivers and antennas is in order. A lot has been written on this subject in other articles Ref. 2 gives a few examples. Except when a good quality dedicated receiver is used such as an "MN26C compass receiver" most ordinary receivers won't pick up much using a simple antenna. This lack of activity with simple antennas is partly because of interference (cross modulation) from strong signals from the broadcast band and partly because the random length of wire has a high impedance and the receiver has a 50 ohm input. Almost any receiver, which covers LF, will pick up a great deal if a highly selective antenna tuner or coupler is used. I usually use an antenna tuner with the main antenna connected as a Tee but some people prefer an active whip antenna or an active loop antenna. Active short e-field (vertical) antennas are said to have an advantage in that they do not pick up noise in the near field as strongly as the main field.

I can't speak with much experience with these types of antennas at this instance but improved performance of small antenna elements may simply depend upon where it is placed in the back yard in relation to the noise source.

The use of weak signal techniques and QRSS

There are several softwares available for use in computers, which use the sound card as a modem. They process the signal using fast Fourier transforms to show a sustained single frequency signal as a line on the screen. Argo is most commonly used and this has a range of time constants covering times from 3 second dots to 120 second dots. Argo is free ware and is available from a site www.weaksignals.com. The input to the sound card is at audio frequency. In my case I use an FT990 set on CW, when I set the receiver to the nominated frequency the audio tone comes out at 700 Hz.

These weak signal techniques are similar to methods used by amateurs for E.M.E. and meteor scatter techniques used on UHF and PSK used on HF.

The transmission of very slow morse known as QRSS can be as morse code with a single frequency and dots and dashes in the standard manner or more usually, frequency shift morse code is used. QRSS FSK seems to be a new invention. In it, all the dots are the same length (e.g.. 120s) with no spaces in the letter. The morse is sent with a higher and lower frequency, the higher dots representing dashes and the lower dots representing dots.

See the examples. The result on the screen is intended to be read by eye. There are softwares that have text capability one of which is known as Jason.

The transmitted frequency and the receiver must be very stable over the period of the transmission. Any morse transmission has to be keyboard entered with appropriate QRSS software. It is quite impossible to hand send or ear read this mode. The receiver for QRSS must be of high frequency stability. Modern transceiver or receivers having a "master oscillator" to lock all local oscillators and BFO and having a frequency stability of 10 ppm are best for the job. These rigs are the type that offer a TCXO or OCXO upgrade to 0.5 ppm although the upgrade does not seem necessary on LF. Of course the receiver must be capable of reception down to 100 kHz to cover the 136 kHz band. For transmission, there is a software known as qrs205.

The main advantage of QRSS is that it can receive signals well below the noise level compared with audible modes even when using a narrow CW filter. Up to -20 to -30 dB improvement is claimed for 120 s. dots. Another advantage is that it can separate the main signal from an interfering signal even when the interfering signal is less than 1 Hz from the main signal. The Argo screen can show several signals in the spectrum of the display and it is therefore easy to pick out the required signal. By comparison if a single very narrow band pass receiver were only used it would be almost impossible to pick out the required signal.

The use of weak signal techniques does cause some differences of opinion in amateur circles. Some people quite interested in LF either do not like the use of computers in radio reception or they do not have the capability in their shack while others who have the capability but are not interested in LF. This division of opinion occurs both here and in New Zealand. If you can't use good old hand sent CW then it isn't worth using. I personally am not very keen on computer aided techniques but at least they do allow you to get an idea as to where you stand with signal level. For example, if the signal is readable with 1 watt radiated power with QRSS 120 second dots you could say that it might be readability 5 with 1 kW and using hand sent morse (actually 1 kW radiated power is a bit beyond our capability but QRSS is quite useful for people who like breaking records). If the QRSS signal is readable with 3 second dots it is reasonable that quite a good QSO could be made even if a bit slow.

Practical results with transmissions from Quartz Hill

Quartz Hill is an area about 15 km South West of Wellington and overlooking Cook Strait. The area was used by the New Zealand Broadcasting service as a receiving station and by the New Zealand Post and Telegraph Department for fixed and maritime mobile services.

The Wellington Amateur radio club had been looking for a site for a club station when in 1996 the club learned that the broadcast receiving station was to be relinquished and sold to the Electricity Commission of New Zealand. The club negotiated with the new owners to manage the site and use the buildings until required. The main amateur radio activity on the site has been the construction and use of Vee beams for HF and a rather large end fed long wire inverted Vee for 160 m. The 160 m. antenna made the basis of an antenna which has been used by the LF

group. On 2200 metres the antenna is basically an end fed length of wire with some vertical component approximately 1/10 of a wavelength long. The club station has the special call sign ZL6QH.

About 2 years ago a number of members of the LF group using a station at Quartz Hill with the call sign ZL6QH began making tests using QRSS on several frequencies around 184 kHz. The tests were made on pre-announced Saturday nights and were carried out between NZ sunset and sunrise with the hope of being copied in America or Europe. The author has copied some of the transmissions here in Melbourne.

Last year the Wellington LF group obtained permission to operate in the European LF Amateur band on a frequency of 137.7888 kHz. The group use an EIRP is 5 watts on 180 kHz and 4 watts on 138 kHz.

So far the results from Quartz Hill have been extremely good. Signals from Quartz Hill were originally transmitted on 174.4 kHz and since December 2001 transmission on 137.7888 kHz. The good results from Quartz hill are probably due to the use of their large antenna.

When transmitting a signal intended for very long distance, 120 second dots with 0.4 Hz frequency shift is used. The transmission from Quartz Hill send only the letter Q. The letter Q consists of two up dots, one down dot and one up dot, see examples. Faster transmission was intended if good reception was indicated. Transmissions from Quartz Hill have been received at several trans. Pacific locations mainly just before dawn at the receiving location. The signals are always detectable in Melbourne from just before sunset.

Four Argo screens are shown here as typical examples, Figs 1, 3, and 4 are for reception at the authors QTH, they are - Fig 1. Reception of ZL6QH on 30th June 2001 at approx. 8.0 pm local time on 184.4 kHz, 1 Hz shift (note 700 Hz offset in receiver when receiving CW). The transmission is at 120 Hz dots and the reception is as for 10 second dots. Note that this is a strong signal.

Discussion

1. Figures 3 and 4 represent reception from ZL6Q on a daylight path and a night path. According to calculations of path loss (see table below) winter daytime ionospheric propagation is quite possible. The result shown in these tests indicate that the daylight path is not as good as expected.

   The following are the calculated path losses, which are in addition to the normally expected losses based on the normal spreading and geometry of the path. This is based on the following, a path length of 2568 km, reflection layer height, day 75 km. and night 90 km. They consist of ground loss at the low launching angle modified by the effect of convergence and loss in the

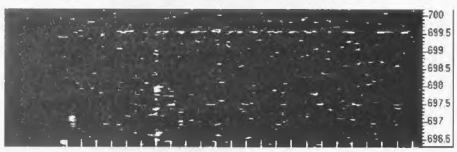

Fig 3 Reception of ZL6QH on 21st September 2002 at approx. 3.00 pm local time on 184.4 kHz and 2 Hz shift, this was an all daylight path. The transmission and Argo setting are for 30 second dots. The dashes are at 699.5 Hz and the dots at 697.5, other lines are interference. Reception at in the next time period on 138 kHz was similar. While a winter ionospheric path should be possible this result was about readability 3. The ticks are 60 seconds part.

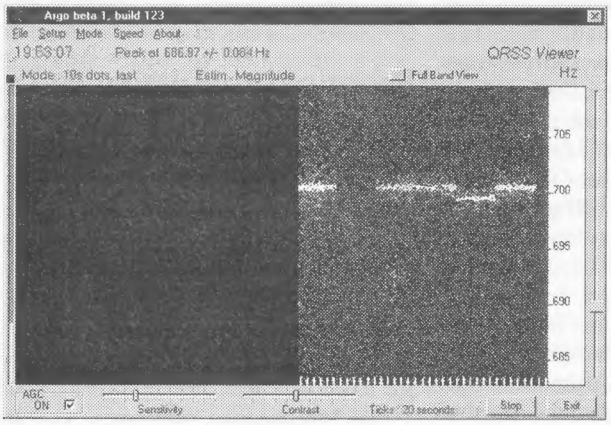

Fig. 1 shows the full screen, the subsequent diagrams as half screen.

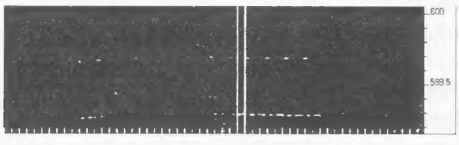

Fig 2 This is an Argo trace taken by Steve VE7SL just before dawn of ZL6QH on 22nd September 2001 on 184.4 kHz. The transmission and Argo setting is for 120 second dots and 0.4 Hz shift. Note that the Trace is inverted with the dots at the top, this is because of inversion in Steve's receiver set up. The two vertical lines are calibration line 240 seconds apart and the ticks are also 240 seconds apart.

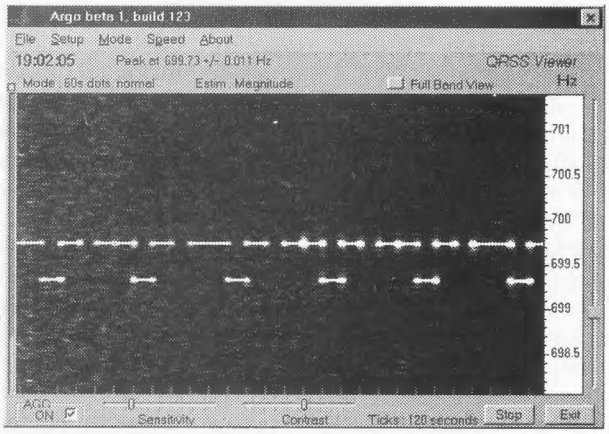

Fig 4 Reception of ZL6QH on 21st September 2002 at approx. 7.00 pm local time on 137.7890 kHz and 0.4 Hz shift. The transmission is at 120 second dots and Argo setting is for 60 second dots and 120 second ticks. This is a very strong signal. The Argo was later set as for 3 second dots and the signal was still very clear although, in this case, the frequency shift was too small for 3 second dots setting. The signal would have been readability 5 at 3 second dots and would have been easily copyable by ear in a quiet location. On this occasion there were no reports of long distance copy.

reflection coefficient of the ionosphere. See Ref. 3.

Additional loss on the darkness path on 138 kHz - 13.5 dB
Additional loss on the day light path for a winter day on 138 kHz - 24.4 dB
Additional loss on the darkness path on 184 kHz - 18.0 dB
Additional loss on the day light path for a winter day on 184 kHz - 33.0 dB

Table 1

From this theoretical calculation the daylight path should have been quite good on 138 kHz. This did not agree with the observed result but more testing is required to obtain a better average result. Calculations indicate that surface wave would be too far down even 138 kHz. Even a path over seawater would not be any use.

2. The improvement in readability using Argo was enormous even on 3 second dots. There is a lot of spurious carrier interference at this QTH as well as the usual atmospheric noise and man made noise and this makes it very difficult to hear anything by ear. If a comparable narrow band filter were available in a receiver (say .01 Hz wide for example) it would be almost impossible to find but still uncopyable because the ear is unable to differentiate between the noise and the signal. Therefore is there anyone versed in information theory who could analyse these results to show the benefits of using this type of DSP. This could be an interesting exercise for someone doing a university thesis.
3. One additional reason why DSP using fast Fourier transforms will work in this case is that "low frequency" electromagnetic signals propagate with a very high phase and frequency stability. This method could not be used on HF because of multipathing causing continual phase instability. It would be interesting to test the method on MF namely 160 metres and see what improvements in readability could be made using QRSS.

References

1. "The Day we crossed the Tasman", John Adcock VK3ACA. AR, April 1993. See also "VK Amateurs on 196 kHz", Don VK3BDJ, "Amateur Radio Action" September 1992.
2. LF Scene. Break-In August 1996 and May 1997.
   An active loop converter for LF Bands, Lloyd Butler VK5BR. AR July 2000, see also references in the article.
3. "Propagation of Long Radio Waves", John Adcock VK3ACA, Amateur Radio June to September 1991. This article is in the web sites with corrections and updates: -
   www.lwca.org/library/lfprop/adcock/lfprop1.htm
   www.lwca.org/library/lfprop/adcock/LFEXTRA.htm
   Also visit the "Long Wave Club of America". www.lwca.org/

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Mount Gambier Convention June 7-8 2003

The South East Radio Group VK5SR will again be hosting the

Annual Radio Convention

&

Australian Fox Hunting Championship

To be held over the Queen's Birthday weekend 7-8 June

The venue remains at the A&H Halls, the Showgrounds, Mt Gambier

For Table bookings or further information please contact SERG President Wayne VK5ZX on 08 87254335 or 0407 719808

600 metres and beyond:
A long wave adventure

Developments are currently taking place in the low frequency spectrum, an area long neglected by amateurs. *Dale Hughes VK2DSH* shows that amateurs can still be in the forefront of technical advances.

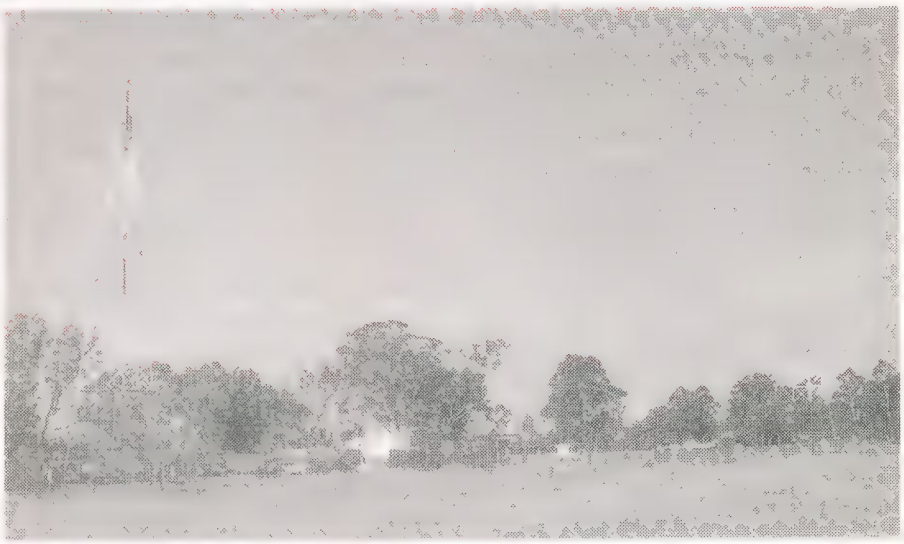

Figure 1: the NDB at Canberra Airport, one of many similar beacons scattered around Australia

Radio technology is now over 100 years old. During that time, it has progressed from spark transmitters and 'cats whiskers' to the latest solid-state technology operating at 100 GHz and beyond. Early intercontinental transmissions took place at low frequencies, which required huge antennae and high transmitter power. This technology was soon overtaken by short wave systems, which could provide worldwide coverage using much lower power and much smaller antennae. Amateur radio operators played a large part in opening up the short wave spectrum and we continue to make major use of that spectrum today. However, low frequencies (LF) and very low frequencies (VLF) are still used for many purposes and some countries have LF amateur allocations. For the purpose of this article, I will refer to LF transmissions as those with a frequency lower than 500 kHz, that is, a wavelength longer than 600 metre. The early history of radio is fascinating and I would encourage the reader to read references 1 and 2 as they provide much interesting information and history.

The spectrum below 500 kHz is used by a number of services, some of these are:

- Non Directional Beacons (NDBs) are used by aircraft for navigation. In Australia, NDB's occupy a range of frequencies from 200 kHz to 450 kHz. Their location can be identified by the two or three letter code that is transmitted repeatedly. NDB's are easily heard using simple receivers and a small antenna. More sophisticated receiver systems can receive NDB's over ranges of up to 2000km. From my location in southern New South Wales, I can receive NDB signals from New Zealand to Woomera in South Australia.

  Some NDBs transmit terminal information by voice. For example:

Terminal	Frequency	Call sign
Canberra	265 kHz	CB
East Sale	350 kHz	ESL
Wagga Wagga	221 kHz	WG
Richmond	347 kHz	RIC
Nowra	359 kHz	NWA
Edinburgh	311 kHz	EDN

  Terminal information gives weather and runway information for the site. Figure 1 shows a typical NDB transmitter site.
- Standard time and frequency transmissions are transmitted by a number of nations on low frequencies. In Australia, time signals can be heard on 40.000 kHz (JJY Japan) and 60.000 kHz (WWVB USA). JJY transmits its call sign in Morse code at 15 minutes past and to the hour. These signals are easily recognised by the time pips sent every second. The pips vary in length, and can be decoded to give the time. Transmissions are also made on 25 kHz, 75 kHz and 77.5 kHz from Europe.
- Navies of many nations use low frequency systems for reliable long-range communications. These signals are very strong and easily received. They are all encoded, however some of them are still use Morse code and transmit their call sign on a regular basis. Presently the Australian Navy transmits on approximately 13 kHz from the former Omega facility near Sale in Victoria. Signals are also transmitted from North West Cape in Western Australia. The Indian station VTX3 is occasionally heard on 18.2 kHz transmitting fast Morse code along with its call sign at regular intervals.
- A number of commercial broadcasters transmit on LF, mainly from Europe. Their carriers can be sometimes heard in this part of the world. So far, no program material has been received at this location.
- LF Amateur allocations exist in a number of countries e.g. New Zealand, USA, Great Britain and

some European countries. In addition, several Australian amateur operators transmit using special scientific class licences on various spot frequencies.

- While not a service, natural radio signals exist at VLF. Whistlers and other phenomena can be used to probe the ionosphere and are a topic of active academic research. Several web sites exist which are devoted to monitoring these signals.

Amateur activities

Receive only activities can be as simple as listening and logging NDB's and other transmissions. There are several web sites devoted to reception of LF and VLF signals, these sites offer much information on what signals can be heard as well as various reception techniques.

As has happened in most other areas of life, the computer is making it's presence felt and a number of programs for reception and transmissions of LF and VLF signals are available. These programs are designed to extract signals from a very noisy reception environment and can enable signals to be received that would be inaudible to the ear. Software for reception and transmission of LF and VLF signals can be downloaded from a number of web sites, see reference 4 for details. These programs are discussed in a later section.

Receivers

It is relatively easy to build LF receivers and transmitters. Such equipment does not require sophisticated test equipment to get going, however there are some subtleties to designing such equipment. In important fact to consider is the receiver dynamic range as weak and strong signals can be very close together. Avoiding inter-modulation depends upon the ability of the receiver to handle strong and weak signals at the same time.

A number of LF converters, loop antennae and transmitters have been described in Amateur Radio magazine ; reference 3 lists some of these. These articles show the 'state of the art' for home made LF equipment, and indicate what is possible to build. Some operators make use of Selective Level Meters that were formerly used for long line carrier systems. Such instruments make sensitive and stable receivers.

Antennas

A suitable antenna is critical for reception of LF and VLF signals. For amateurs, there are two that are commonly used:

- The loop antenna.
- The active whip.

Loop antennae offer the advantage of being able to maximise signal strength or null out noise by rotation. However loop antennae need to be tuned for best efficiency.

An active whip antenna consists of a vertical rod, typically 0.5m to 5m long, with a low-noise amplifier at the antenna base. This type of antenna does not require tuning, however it can be more susceptible to electrical noise than the loop antenna. As I live in an electrically quiet location I chose to use the simpler whip type antenna 4 metres in length.

From reference 5, p 228, the radiation resistance of a short vertical antenna over a perfectly conducting ground is given by:

$R_r = 40\ \pi^2\ (h/\lambda)^2$

And its capacitance (in pF) is given by:

$C_a = 24.2\ h/(\log(2h/a) - 0.7353)$

Where h = The antenna height (m)
λ= The operational wavelength (m)
a = The whip diameter (m)

While the above assumes a perfect ground, which is not usually the case, the values obtained are indicative of the true electrical parameters. Thus a four meter whip, with a diameter of 10mm, at 200 kHz (λ = 1500 m) appears as a

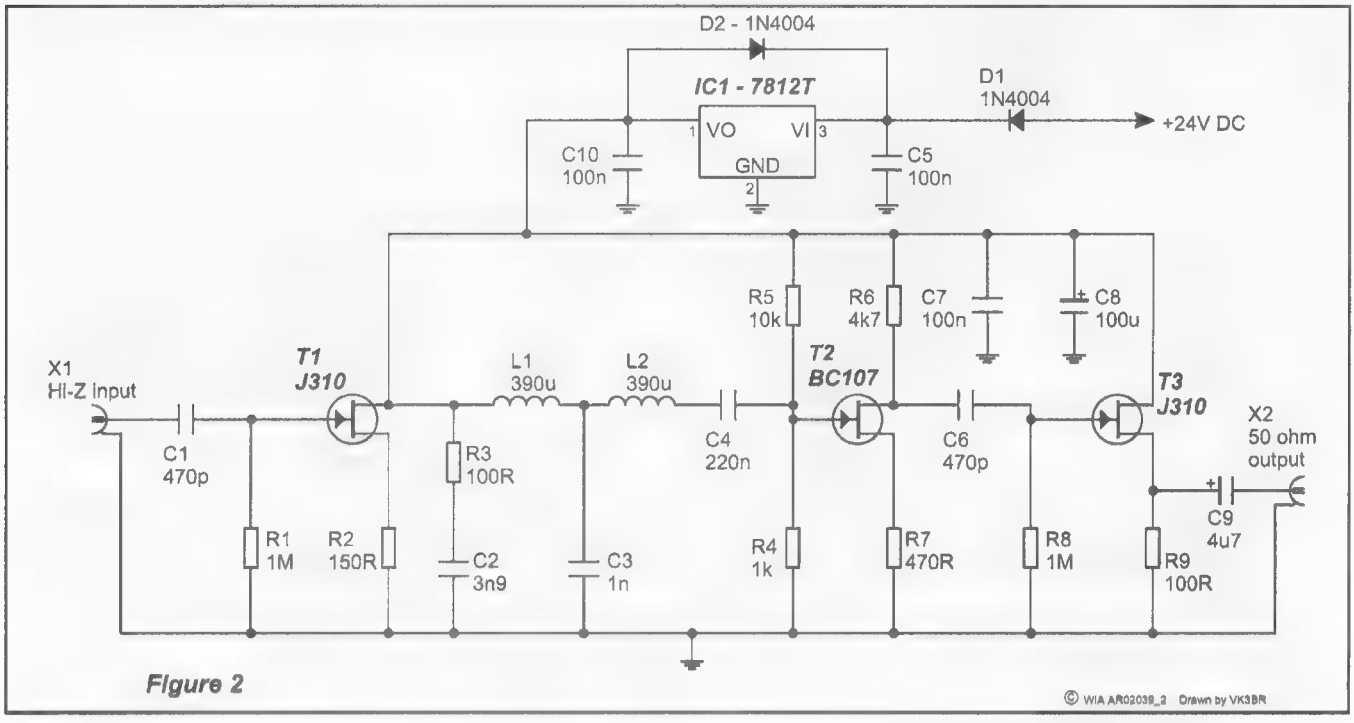

Figure 2. A pre-amplifier suitable for low frequency active whip antenna.

0.0028 ohm resistor in series with 44.6 pF capacitor.

It can be seen that the equivalent circuit of the whip is a low value resistance in series with a small value capacitor. Thus some sort of impedance matching and pre-amplification is required. An amplifier with a 50 ohm input impedance would 'short' out the signal from the antenna, so high input impedance is required.

A suitable circuit is shown in figure 2. The input stage (T1) is a source follower and its' input resistor, R1, sets the input impedance. The source follower then feeds a low pass filter with a cutoff frequency of 400 kHz so that strong medium wave broadcast stations are significantly attenuated, thus reducing inter-modulation effects. Figure 3 shows the measured frequency response of the unit. A small amount of voltage gain is provided by T2, T3 provides a low impedance output for driving a coaxial cable. The circuit should be mounted at the base of the whip antenna for best results. The overall voltage gain is about 2 or 6db, however the power gain is very high and the circuit is very effective when used with a whip antenna.

With this pre-amplifier, my receiver is capable of receiving LF signals from Japan, America, New Zealand and many parts of Australia. It has very good strong signal capability and does not suffer from any inter-modulation effects from strong NDBs or medium wave transmitters. The unit was built using point-to-point wiring on a length of tag strip and is housed in a small die cast box, which is mounted at the base of the whip antenna.

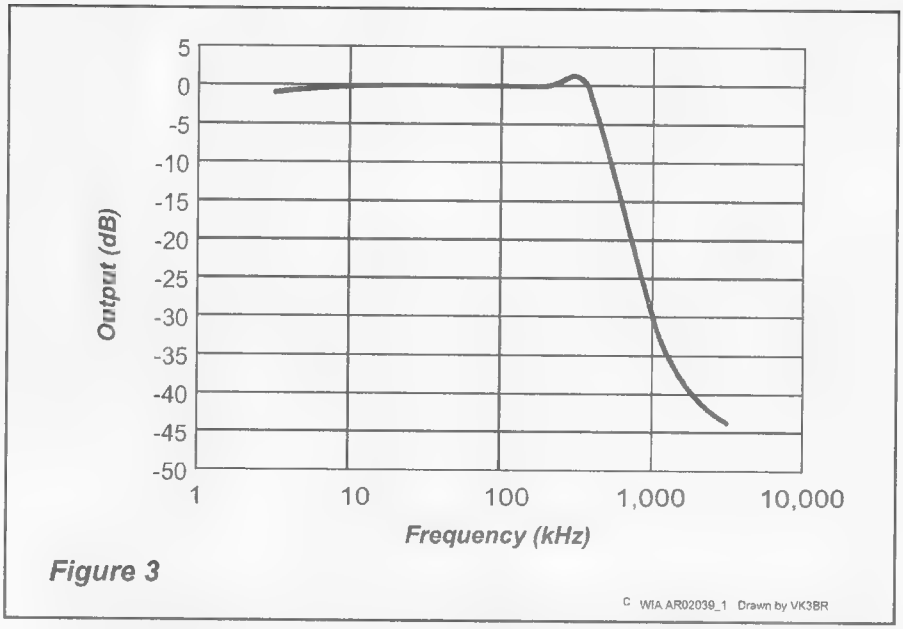

Figure 3. Frequency response of the pre-amplifier circuit.

Unwanted Noise pickup

As noise pickup can be a serious problem at low frequencies the pre-amplifier and antenna can be placed some distance from noise sources so that noise pickup is minimised.

Most computers generate considerable radio frequency interference at low and medium frequencies, so it will be necessary to implement some sort of noise control. I have found the following effective:

- Use a 240 Vac isolation transformer to power the PC and associated monitor.
- Use a separate earth for the radio equipment and computer equipment.
- Supply power to the radio equipment through a high quality interference filter.
- Use an audio isolation transformer between the receiver output and the PC sound card.
- Some PC power supplies are much noisier than others so try swapping power supply modules if noise is severe.
- Build a screened box (Faraday cage) to house the PC, and fit RFI filters or chokes to all cables into and out the box.
- Try changing display settings if the VDU causes interference on desired frequencies.
- If buying a computer, select a unit that is well screened. 'Name brands' usually generate much less Radio Frequency Interference than cheaper types.

Software

Commercial and government LF broadcasters use all the common forms of modulations. Due to restrictions on power and bandwidth, amateurs have developed modulation schemes, which operate with very small bandwidths. This usually means some form of frequency shift keying and using spectral analysis to extract the signal. Several programs are available to the amateur:

- Argo (by I2PHD & IK2CZL)
- Spectran (as above)
- Spectrogram (by R. S. Horne)
- Spectrum Lab (by DL4YHF)

Each program offers the user some different facilities and ease of use. Argo is by far the simplest to use and offers the user preset controls for the popular modes. Spectran is very similar.

Spectrogram was one of the earliest of these programs and it started life as a general-purpose spectral analysis program. It is available in various versions, some of which are more suitable for radio applications than others. Spectrogram offers a convenient facility of being able to record the incoming audio as a wave (*.wav) file. The file can be later analysed or replayed much like a tape.

Spectrum Lab offers a huge range of options and settings; it also has a terminal mode for sending and receiving various modes. It's flexibility and power comes at the price of complexity and it takes some time to master. In addition, Spectrum Lab has a basic 'soft receiver' with which to experiment.

A mode of communications that is growing in popularity is QRSS or very slow Morse code transmissions. In this case, very slow means that each character can take ten minutes or more to send, as the dot length can be 120 seconds or more. Key-down transmits one frequency and key-up transmits a slightly different one. Figure 4 shows a typical display; note that the frequency

spectrum is graphed against time.

What advantage does this mode offer? It means that the transmission occupies a very narrow bandwidth, typically 0.4 Hz, and that the signal can be inaudible, yet receivable using appropriate software. The very slow transmission speed means that the usual aural mode of receiving the Morse code is not practical so that some sort of computer assistance is required. The programs listed above provide that assistance.

Note the very narrow bandwidth as shown by the vertical scale. The narrow bandwidth means that the receiver frequency stability must be very good, excessive frequency drift can cause the signal to quickly drift out of the display range.

A variation of the above display is where the time axis is vertical and frequency is horizontal. In this case, the display is known as a 'waterfall' display. These programs are useful anywhere that very weak signals are received, so these techniques have also been used in EME and HF QRP communications.

These programs can be used to receive ordinary Morse code as well and are especially useful where a number of stations are transmitting on closely adjacent frequencies.

The soft receiver

The idea of a 'soft receiver' has recently been developed. This idea does away with the usual concept of a receiver and instead substitutes a computer, a Sound Blaster card and spectral analysis software which act as a simple receiver. The radio signal is connected to the microphone input of the Sound Blaster. Spectrum Lab contains an interesting soft receiver that demonstrates the idea. The receiver covers the range from DC to 22 kHz and allows the user to tune to a specified frequency and listen to the signal. An adjustable band pass filter is also provided. It's an interesting experience to see the spectrum on the screen and be able to move the cursor to a signal of interest and hear it - and it's all done in software!

The receiver is tuned by moving the small diamond shaped cursor on the frequency scale. The signal may also be heard via the sound blaster card. An adjustable band pass filter is available to help extract signals from the noise. The receiver is set to 14.8 kHz, at the time a navigation signal was heard from Russia. In figure 7, the signal can be seen as a series of pulses.

The continuous lines at approximately 13, 18 and 20 kHz are naval radio transmissions. The thin line near 16 kHz is interference from the 15625 Hz TV line frequency. The slow pulse groups at approximately 10 and 15 kHz are VLF navigation signals originating from Russia. The yellow lines right at the bottom of the display are from the 50 Hz mains and it's first few harmonics. This image was recorded by connecting the four metre whip antenna and pre-amplifier to the microphone input of the Sound Blaster card in the PC - very basic soft receiver.

Conclusion

Low frequency transmission and reception are a fruitful area for amateur experimentation and many operators through out the world are enjoying developing and exploiting new techniques of communications. Long range communications are possible using relatively simple equipment in conjunction with sophisticated signal processing software. Hopefully Australian amateur operators will soon have transmit privileges and will be able to take part developing in two-way communications using a very interesting part of the radio spectrum.

References and further information:

(1) *Early Radio - In Marconi's footsteps*, Peter R Jensen.

(2) *From the Wireless to the Web*, Peter R Jensen.

(3) *Amateur Radio* LF articles:

Sones G, *Active Door Loop Receive Antenna*, October 2001.

Rogers R, A *Low Frequency Beacon Transmitter*, February 2001.

Butler L, *The Active Loop Converter at VLF*, January 2001.

Butler L, *Antenna Noise and Signal Canceling at LF*, December 2000.

Butler L, *A HF to LF Transmit Frequency Converter*, November 2000.

Butler L, *An Active Loop Converter for the LF Bands*, July 2000.

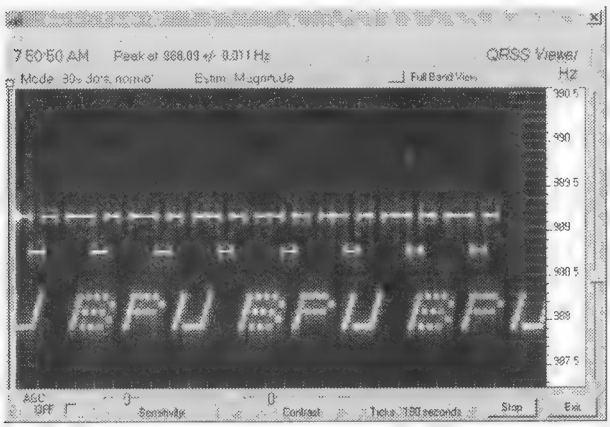

Figure 4. Argo display of QRSS (upper trace) and multi-frequency Hellschreiber (lower trace). Image courtesy of ZL1BPU.

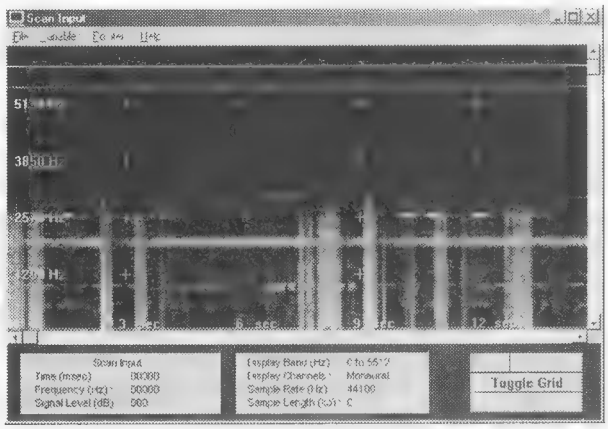

Figure 5. A Spectrogram screen capture of a number NDB's transmitting their callsigns. BN (Brisbane, QLD) over WYY (Wynyard, TAS) on 302 kHz and GTH(Griffith, NSW) on 305 kHz are clearly visible.

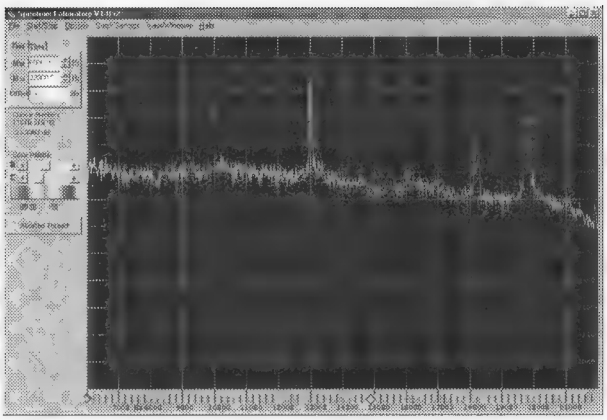

Figure 6. Spectrum Lab Soft Receiver front panel.

Diamond D, *LF Receiving Converter with Loop-stick Antenna,* May 2000.

Butler L, *An experimental Low Frequency Band Transmitter,* February 2000.

Butler L, *An LF Antenna Bridge,* October 1998.

(4) Useful LF web sites:

Argo and Spectran software can be downloaded from:
http://www.weaksignals.com/

Spectrogram can be obtained from:
http://www.monumental/rshorne/gram.html

Spectrum lab can be downloaded from:
http://www.qsl.net/dl4yhf/

Wave files of various transmission modes can be found at:
http://marconi.careless.net/hadarc/digsound.html

This is useful in identifying particular signal types and sources. A wide range of Sound Blaster programs for various modes of reception and transmission can be found at:
http://www.muenster.de/~welp/sb.htm

Long Wave Club of America web page contains much long wave information, articles and links to other LF sites:
http://www.lwca.org/

WWVB time signal information can be found at:
http://www.boulder.nist.gov/timefreq/stations/wwvb.htm

JJY time signal information (in Japanese only) can be found at:
http://jjy.crl.go.jp/JJY-pamp/jjy.html

(5) *Communications Receivers, DSP, Software Radios, and Design,* Ulrich Rohde and Jerry Whitaker.

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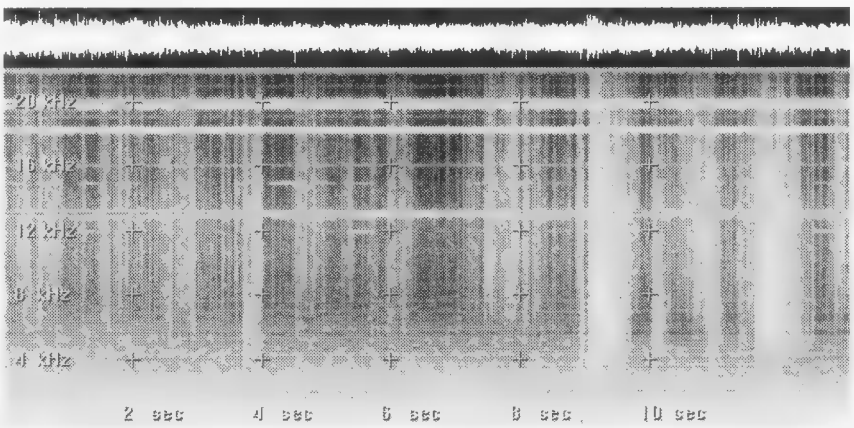

Figure 7. VLF signals between 0 and 22 kHz, seen using Spectrogram. This image was created using the Spectrogram screen capture facility.

Silent Key

Joseph Nelson VK2KJN

Joe Nelson passed away on May 16th, 2003 in hospital after a long illness. He was 76.

He loved radio and in his boyhood days he built crystal and valve sets as a hobby. In his retirement, he qualified as an Amateur in 1996, after doing courses with the Hornsby Club, HADARC, of which he was a member.

He operated on HF and was a revered participant in Col's Net, talking each weekday to other amateurs living in different parts of Australia. He met each month with the Amateur "Vets" at WIA House, Parramatta, enjoying the company of other "hams" over lunch.

For many years, Joe worked as shift foreman electrician at Lysaghts Wire Plant at Fivedock in Sydney, but did his training and apprenticeship in Melbourne

Joe helped at the Volunteer Coastal Patrol Radio Centre at Terry Hills, doing his weekly early morning shift. A highlight of his retirement was his participation as a volunteer at the Sydney Olympic Games. He worked in the "Communications Centre" in an organising role and continued in the same way during the following Para-Olympics.

He loved fishing and swimming, doing laps at the Ryde-Eastwood Gym, Pool, sometimes three times a week. He was an avid follower of AFL Football. He was a gentle and kind man, always ready to help others. He leaves a fine family, his wife Joyce, daughter Sue, and three sons, Jim, Peter and Bill.

Joe will be missed by his many friends and we extend our sympathy to his family.

Submitted by John Stacy VK2JJS

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An experimenter's LF/MF receiver

Dale Hughes VK2DSH

The idea for this receiver grew out of an article by Lloyd Butler, VK5BR, in the December 1989 issue of Amateur Radio. The article (1) described a LF/MF receiver which used a resistance tuned local oscillator and operational amplifiers for the gain stages. The design was appealing because of its simplicity and ease of alignment, and the resulting receiver was small enough for portable use.

My initial intent was to duplicate the receiver, however several of the crucial parts appeared to be difficult to obtain. I then realised that this presented an opportunity to try out some circuit techniques that might be interesting, these being:

- A local oscillator using Direct Digital Synthesis (DDS) technology. I had recently been experimenting with DDS technology in a test oscillator (2) and was confident that a DDS design would work very well. An accurate 50 MHz crystal oscillator module that provides a high degree of frequency stability and resolution clocks the DDS. In this design, a frequency step of 100 Hz has been provided.
- RF amplifiers using 'noiseless feedback', where gain stabilization is by means of transformer coupled negative feedback. This circuit topology is reputed to have excellent signal handling ability, wide bandwidth and a low noise figure. It also has the advantage of presenting a 'two way impedance match'; that is, the input impedance is the same value as the output impedance. In this case, the impedance is 50 ohms. These features come at the cost of increased power consumption. Details of 'noise-less feedback' amplifiers can be found in references (3), (4) and (5). The amplifier used in this receiver is a push-pull design that performs very well, giving a voltage gain of approximately 9, and handling the high signal levels found in the low and medium frequencies with ease.
- A switching type mixer based on a CD4066 CMOS analog switch driven by a 74HC74 flip-flop that generates an accurate square wave. The mixer is broadband terminated by a differential input, high frequency operational amplifier.
- The detector is a so-called 'supergainer' regenerative detector (6) that can give considerable gain, up to the point of positive feedback. When oscillating, the detector performs well as a CW and SSB demodulator. Prior to the onset of oscillation, the detector acts as a standard 'square law' envelope detector.
- Use readily obtainable operational amplifiers for the IF stage.
- Use an 'Active Whip' type antenna, that is a short vertical element with an impedance converter which converts the high impedance of an electrically short whip to the 50 ohm input impedance of the receiver. References (7), (8) and (9) provide some background in the techniques used for active whip antennas and several different designs are discussed. The most important factor in the design of active whips is dynamic range and noise figure.

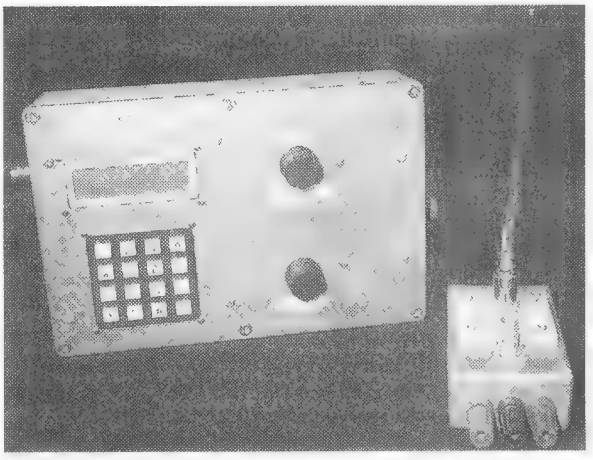

Figure 1. The complete receiver and the portable version of the active whip antenna.

The final design of the receiver uses all of the above ideas and the result is a receiver that has the following specifications and features:

- A frequency range of 10 kHz to 2000 kHz, in 100 Hz steps,
- Excellent dynamic range,
- Low noise,
- High sensitivity,
- Demodulates CW, SSB and AM,
- Adjustable RF step attenuator,
- Easy to use and portable.

The receiver is easy to operate, with a minimum of controls. Frequency selection is by means of a keypad, where the frequency can be entered directly. The keypad also allows the user to step up or down in frequency in 100 Hz steps. The RF attenuator is also adjusted from the keypad, the user can select one of four attenuator settings: 0 db, 6 db, 12 db or 18 db. The only other controls are the volume control and the regeneration control. The regeneration control gives the user control over the detector gain and increasing the regeneration can significantly enhance weak signals. CW and SSB signals can be resolved by advancing the regeneration control up to the point of oscillation where the detector becomes a self-oscillating product detector. In use, the control is very smooth and the detector gives a very high quality audio output. In addition to the foregoing, when receiving a strong AM station, the detector can act in an 'injection locked' mode, where the oscillating detector will lock to the incoming carrier. The

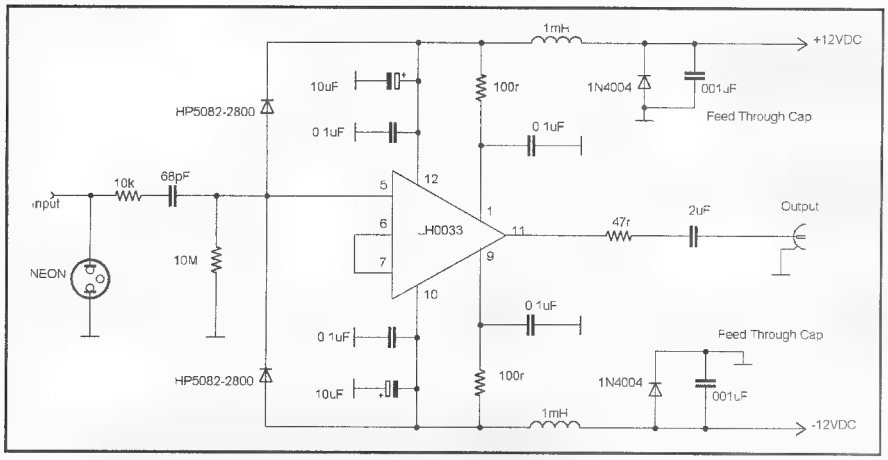

Figure 2. Active antenna schematic diagram

detector performance is very good in this mode, with noise and distortion at a very low level.

The receiver sensitivity is as good as it needs to be, DX AM broadcast stations are easily received. In the LF region, NDBs over 1200 km distant have been heard and the time signals on 40 kHz and 60 kHz are heard most evenings. The 60 kHz signal can only be heard if the receiver is well away from any television set, as a harmonic of the 15625 Hz line oscillator will completely swamp the 60 kHz time signal. Reception down to 10 kHz is possible and the Russian 'Alpha' navigation signal can occasionally be heard, as can the various naval transmissions below 25 kHz.

The step attenuator is useful when receiving a weak signal adjacent to a strong signal, and the receiver noise figure is low enough to permit using the maximum attenuation (18 db) setting to overcome any overloading problems. As the receiver has no AGC system, the step attenuator can be used in conjunction with the regeneration control to reduce the volume of powerful stations.

This article should be considered more as a description rather than a detailed construction article, thus no printed circuit board artwork is given and some of the parts used might be difficult to obtain. The original receiver was built on 'Vero' type prototype boards, or using 'ugly' type construction. When the design was more-or-less complete, circuit boards were designed and made. Even then, changes were made to the final circuit as receiving experience dictated circuit modifications.

Due to the presence of high-speed digital circuitry in the micro-controller it is very important that special attention is paid to filtering and de-coupling of all power supply and control lines. The completed receiver makes extensive use of feed-through capacitors on all power supply connections, relay control lines and audio circuits. In addition, the RF circuitry is well screened from the digital circuitry by two layers of thin circuit board material. Inadequate screening, filtering and mechanical construction will result in inferior performance of the completed receiver.

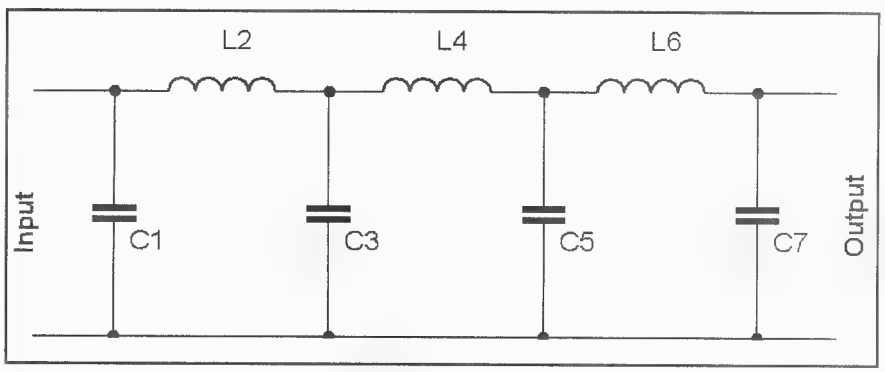

Figure 3. Prototype filter schematic diagram. The front end requires four such filters with the component values shown in Table 1. (See figure 4.)

Detailed circuit description

The receiver can be broken down into a number of sections:

(1) The active antenna,
(2) The 'front end' filters, attenuator and RF amplifier,
(3) The mixer, IF, detector and audio amplifier,
(4) The DDS local oscillator.

Each of these parts will be described in the following sections.

Note that the supply to the receiver is split, i.e. +/- 6 volts, this simplified biasing of the operational amplifiers in the IF and DDS sections. The active antenna uses a split 12 Vdc supply, i.e. +/- 12 volts, and it can be run from the +/- 6 volt supply if required, although the dynamic range of the buffer is reduced and the potential problems due to overload and inter-modulation are increased.

The active antenna

As the antenna is a short vertical whip it is necessary to employ some form of impedance matching between the whip, which has a very high impedance, and the 50 ohm feed line. This design uses a LH0033 FET input, fast voltage follower that has a very high input impedance and a line driver output stage. The active antenna module is fitted with lightning protection in the form of a neon tube between the antenna input and ground, the buffer input is protected by reverse biased diodes which conduct when the input voltage exceeds +/- 12 Vdc, a series resistor limits the transient current flow to a small value. Two of these units have been built, a roof-mounted unit with a 1.5 m whip and another portable unit with a shorter, telescopic antenna and no lightning protection. (As shown in figure 1.)

Inter-modulation products can be a problem with active antennas, especially in areas where there are multiple high power transmitters. This design is reasonably robust as the standing current of the FET stage is 10 mA, and the supply voltage is +/- 12 Vdc,

This results in a buffer that handles high-level signals without generating significant inter-modulation products. The output impedance of the complete active antenna is 50 ohms, so it presents a good match to the following low pass filters. Shunt capacity on the antenna

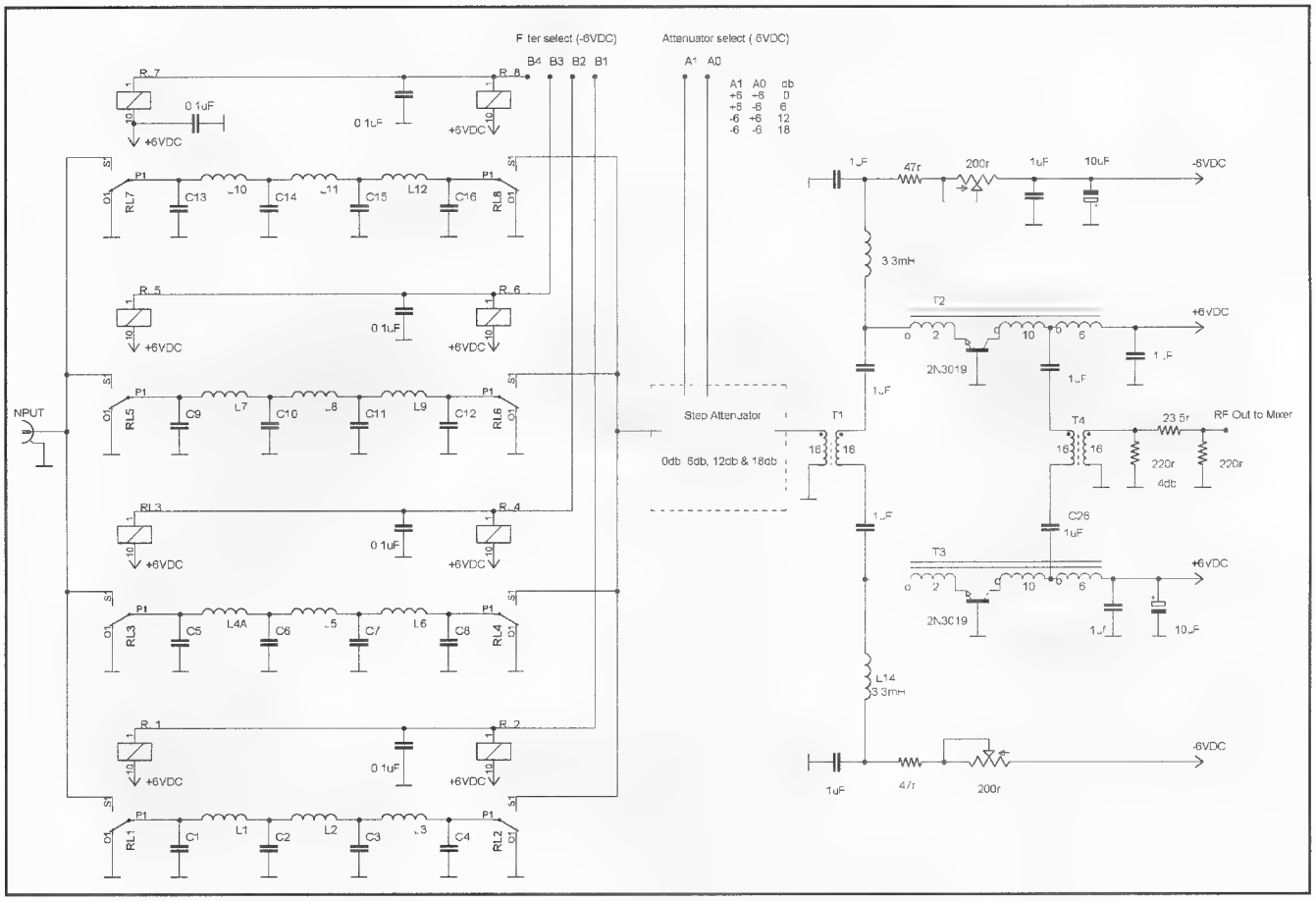

Figure 4. Front-end schematic diagram. The low pass filter component values are taken from Table 1. Transformers T1, T2, T3 and T4 are wound on Amidon FT-50-77 ferrite cores. See figure 5 for details of the step attenuator.

input should be keep to a minimum if reception down to the lowest frequencies is required.

The front end

As the receiver is a superhet design, some form of image frequency rejection is required. A conventional receiver would use a tuned circuit that would reject the image response 910 kHz (twice the intermediate frequency) above the wanted frequency; such a system is easily achieved when a multi-ganged variable capacitor is used. In this design there is no variable capacitor so it was more difficult to arrange a variable frequency tuned circuit. Instead this design uses a low pass filter, which is selected according to the frequency of interest. In this case, the low pass filters have cut-off frequencies of 365 kHz, 663 kHz, 1210 kHz and 1960 kHz. The filters are 7 element designs taken from the ARRL handbook (10) and have been selected to use standard capacitor values and hand wound toroidal inductors. Table 1 shows the component values and cut-off frequencies; figure 3 shows the prototype filter design and component identification.

Where n is the number of turns on an Amidon T50-15 toroidal core (Iron powder type core). Fc is the filter cut off frequency, F40 is the frequency at which the filters response is 40 db down

The required filter is switched into the signal path by means of small relays, I considered using diodes to switch the filters into and out of the signal path, but was concerned that diodes might be subject to high signal levels and a potential source of inter-modulation products. Each filter section is short circuited when it is not selected so that spurious filter resonances should not occur. Software examines the selected receive frequency and switches in the appropriate low pass filter. The user has no direct control of the filters.

A constant impedance step attenuator follows the filters and the signal level entering the RF amplifier can be adjusted to suit the listening conditions, four levels of attenuation are possible 0 db, 6 db, 12 db and 18 db. Control of the attenuators is by means of key strokes on the keypad. Details of the attenuator are given shortly.

The RF amplifier uses a pair of 2N3019 transistors in a push-pull noiseless-feedback arrangement. This circuit has the advantage of being able to handle very high signal levels and still operate in a linear region. The circuit has 50 ohm input and output impedances and is well

F_c kHz	F_{40} kHz	$C_{1,7}$ nF	$C_{3,5}$ nF	$L_{2,6}$ uH	$L_{2,6}$ n	L_4 uH	L_4 n
365	580	10	18	31.1	48	34.5	51
663	1050	5.6	10	17.5	36	18.9	38
1210	2130	2.2	4.7	9.27	26	10.8	28
1960	3140	1.8	3.3	5.83	21	6.5	22

Table1. Component values for front end low pass filters.

suited for use in the LF/MF frequency range. With appropriate transformers and transistors, the circuit will operate well into the VHF range. The gain of the circuit is set by the turns ratio of the feedback transformers (T2 and T3) and with the values shown, the circuit has a voltage gain of 9. The 4 dB attenuator at the output of the amplifier is necessary to preserve the high dynamic range of the RF amplifier, as it ensures that the RF amplifier termination impedance is correct.

The bias current is adjusted by means of the 200 ohm potentiometer in the emitter circuit, so that 20 mA of collector current flows in each transistor. Ideally, the transistors would be well matched, however I did not match the transistors and I found that the gain of each 'half' of the circuit was very close. Other suitable transistors would be 2N3866 or 2N4427 devices, depending on availability.

As the ferrite toroidal cores used in the amplifier are conductive it is best to insulate the core with Teflon tape or to use insulated wire; I used wire wrap wire, also known as 'Kynar' wire to wind the transformers. For the inductors in the low pass filters I used enameled copper wire directly onto the painted iron powder cores.

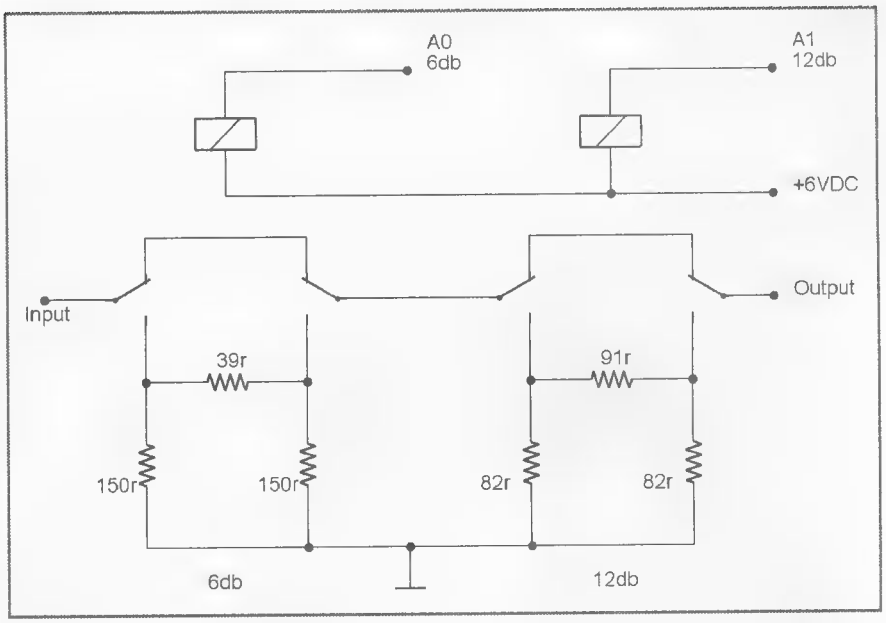

Figure 5. Schematic diagram of the step attenuator between the output of the low pass filters and the RF amplifier input. Other values of attenuation can be used if required.

The attenuator was built on a small circuit board mounted adjacent to the front-end board and the signal coupled via thin co-axial cable. The relays are

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switched according to the level of signal attenuation required:

Attenuation (db)	Relay A0	Relay A1
0	Off	Off
6	On	Off
12	Off	On
18	On	On

Table 2: Attenuator relay selection.

Selection of the attenuator setting is via the keypad. When the * key is pressed, a menu appears on the LCD and the user can select which level of attenuation is required. The current setting of the attenuator is always displayed on the LCD, along with the current receive frequency.

The mixer, IF and detector stage

Following the front end, the signal is passed to the mixer where the 455 kHz IF signal is generated. The mixer is a double balanced design using four analog switches. The switches are driven by a 74HC74 D-type flip-flop that provides an accurate square wave. A Schmidt trigger converts the sine wave output of the DDS oscillator to a logic level signal to drive the 74HC74. The mixer output is terminated by a resistive load by way of the input resistors of the following op-amp (IC4) that converts the balanced output of the mixer to a single ended signal and provides a modest amount of gain.

The ceramic filter that follows the mixer amplifier sets receiver selectivity. The filter I used has a 6 dB bandwidth of +/-3.5 kHz, which is wider than desirable, but it was the only filter I had on hand. Following the filter is an amplifier (IC5) that also provides the correct termination impedance for the filter.

As the receiver was designed to receive CW and SSB as well as AM signals, some sort of BFO was required. After examining the literature, I settled on the 'super gainer' type design that combines an envelope detector as well as an oscillator. When receiving AM, the gain of the circuit is adjusted such that no oscillation occurs. For receiving CW or SSB, the regeneration control is advanced until a beat note is heard. The gain of the stage also changes with the amount of regeneration, for strong signals the regeneration control is

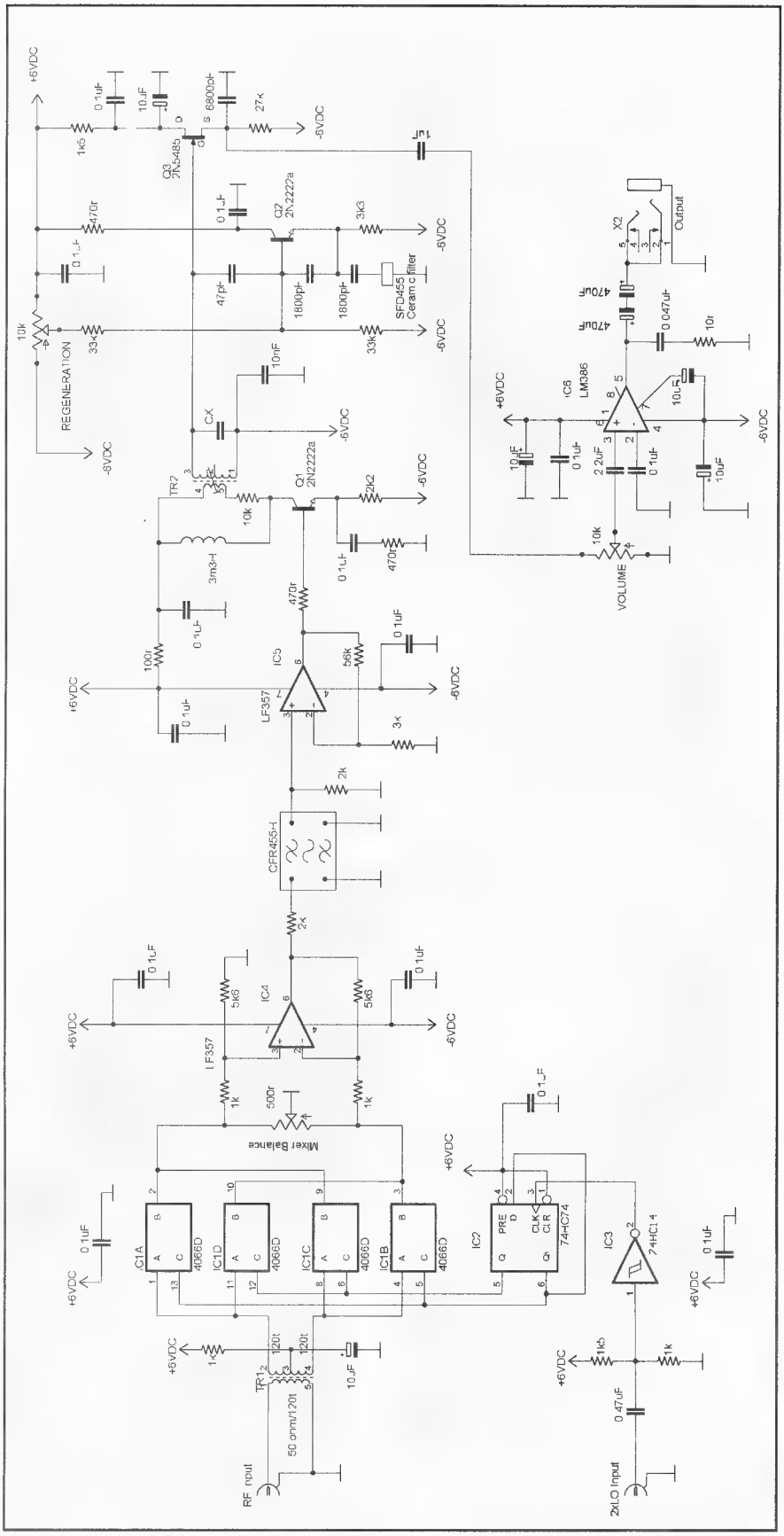

Figure 6. IF and detector schematic diagram.

backed off, maximum sensitivity occurs just prior to the onset of oscillation. The circuit performs very well and the regeneration control provides a wide range of gain adjustment and a smooth transition into and out of oscillation. The schematic diagram shows a two terminal ceramic filter (Murata type SFD455) in the emitter circuit of the oscillator transistor (Q2). This device acts to stabilize the oscillation frequency of the stage and is optional, if not used it should be replaced with a short circuit.

Transformer TR2 is a standard miniature 455 kHz IF transformer, (Cx is internal to TR2) and the output from the final IF amplifier (IC5) is lightly coupled to TR2 using a 10 k ohm resistor. Reducing the value of the coupling resistor makes the regeneration control much less effective, as the tuned circuit will be more heavily damped.

A LM386 audio amplifier has a voltage gain of 50 and will drive a loudspeaker or headphones with ample volume. As there is no Automatic Gain Control it is necessary to be careful when using headphones for listening, as it is possible to tune from a weak station to a strong station with ear-splitting results!

The DDS local oscillator and micro-controller

A Direct Digital Synthesizer is used as the receiver local oscillator. The DDS local oscillator runs at twice the mixer frequency due to the divide by two flip-flop on the IF board. Thus the DDS frequency is:

Flo = 2 (Frx + 455) kHz

Where Flo = Receiver local oscillator frequency

Frx = Receiver frequency

For this receiver the DDS oscillator tunes between 930 kHz and 4910 kHz, as the tuning range is 10.0 kHz to 2000.0 kHz, the required frequency is entered via the keypad and is displayed on the liquid crystal display. An Analog Devices AD 9835 DDS was used, and this chip has a maximum output frequency of 25 MHz when a 50 MHz crystal oscillator is used as the reference frequency. The sine wave output from the DDS chip is amplified by an LM7121 op-amp. The DDS signal is subsequently squared by a Schmidt trigger on the IF board, where the local oscillator signal is divided by two to generate the correct local oscillator frequency.

Control of the DDS, LCD, keypad and relay switching is by means of an Atmel AT90S8535 micro-controller. This chip is a very powerful and easy to use device, readily available from Dick Smith Electronics at reasonable cost. The micro-controller chip controls the input filter selection and attenuator relays and the interface is via a network of feed-through capacitors and opto-couplers. The opto-couplers provide a high level of electrical isolation so that noise from the micro-controller and associated circuitry is not coupled into the receiver. The opto-couplers also allow the 12-volt relays to be controlled from the 5-volt micro-controller circuitry. The opto-couplers used in this design have a high current transfer ratio (100%). If opto-couplers with a lower current transfer ratio are used, driver transistors will be required so that the relays pass sufficient current to operate.

The current version of the micro-controller firmware allows operation of the receiver between 10.0 kHz and 2000.0 kHz, and the frequency can be selected in 0.1 kHz increments. When a frequency has been entered, the setting can be incremented or decremented in 0.1 kHz steps by using 'up' and 'down' keys on the keypad. Thus, it is very easy to fine-tune the receiver.

The DDS and micro-controller are mounted on the same printed circuit board that is mounted on top of the box behind the keypad and display. These components are covered with a screen to minimise interference. All signal and power lines, except the local oscillator output, are filtered using feed-through capacitors. The local oscillator output is connected via small diameter coaxial cable.

The power supply regulator, DDS/micro and opto-isolators are on separate circuit boards, and mounted on the front panel of the receiver box – suitably screened.

Receiver adjustments

There are a number of components that require alignment after the receiver is constructed:

- Adjust the micro-controller and DDS power supply to 5.00 Vdc by adjusting the potentiometer on the LM2941 voltage regulator.
- Adjust the contrast control so that the liquid crystal display can be clearly seen.

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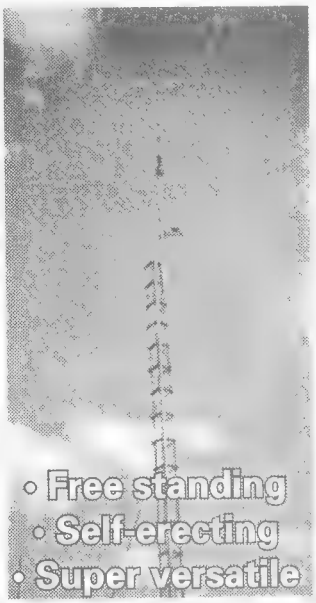

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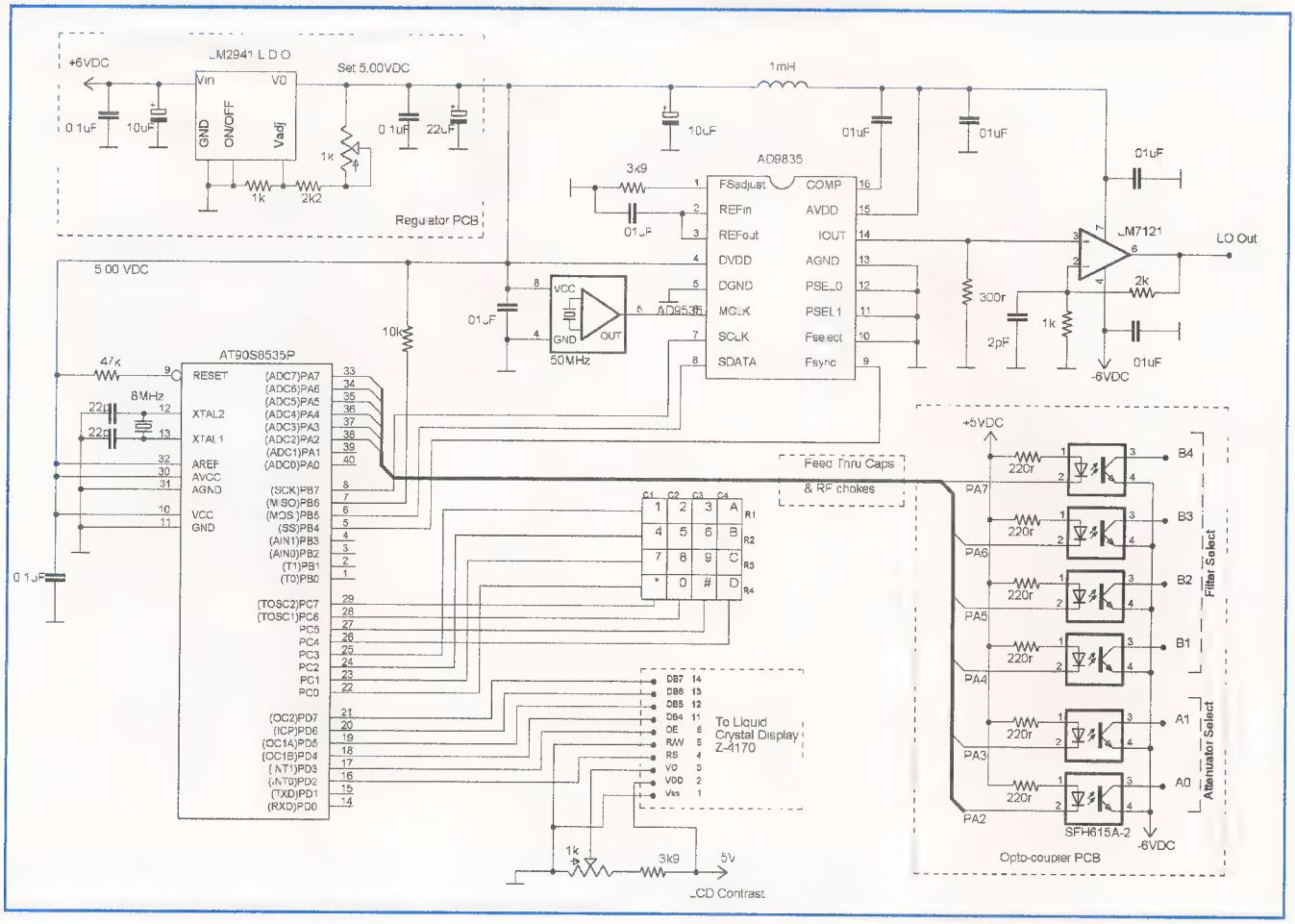

Figure 7. DDS and micro-controller schematic diagram.

- Adjust the 200 ohm potentiometers in each of the RF amplifier circuits so that an emitter current of 20 mA is obtained. This is best done by measuring the voltage across the 47 ohm emitter resistor and adjusting the control until 0.94 volts is measured across the resistor.
- Set the mixer balance control to mid way through its travel. Connect an oscilloscope to the output of the mixer amplifier (IC4). With the receiver input terminated with a 50 ohm load, adjust the mixer balance control so that the noise level measured on the oscilloscope is minimized. The mixer is balanced when this is done.
- Tune the receiver to a weak signal, or inject a weak signal, at approximately 1 MHz. Set the regeneration control to minimum, then adjust the core in the IF detector transformer (TR2) for maximum audio output.

Receiver performance

The receiver performs very well and is easy to use; the DDS gives drift free and repeatable performance. Due to the use of a strong RF amplifier using 'noiseless' feedback, the receiver performs well in the presence of many strong signals. Using the step attenuator to control signals levels into the RF amplifier is essential if best performance is to be obtained.

As the detector is regenerative, its bandwidth can be somewhat narrowed by increasing the regeneration, but better selectivity could be obtained by using a filter with a narrower bandwidth. However, this does not cause any problems in the use of the receiver. As mentioned previously, the quality of the audio output is very good for both AM and CW signals, and medium wave DXing is a lot of fun with this receiver.

Sensitivity appears to be quite adequate, with LF aeronautical beacons being heard over distances up to 1500 km and standard time stations on 40 and 60 kHz being easily heard if atmospheric noise is low enough. The limiting factor appears to be locally generated interference from TVs, computers and the like. At a quiet location away from such noise sources, worldwide reception is possible i.e. reception of JJY from Japan and the Russian signals.

No image responses are possible when using the receiver below 455 kHz as the receiver is working in the 'up-conversion' mode and the low pass filter attenuates the image frequencies. When tuning above 455 kHz image frequency responses are possible due to the broadband input, however the low pass filters and switching software have been selected to minimise these responses.

The disadvantage of using a broadband input is evident when using the receiver above about 1500 kHz. Intermodulation products and noise are apparent and the use of an appropriate band pass filter would be necessary for any weak signal reception.

Components

There are a number of parts in this receiver that may be difficult to obtain from the usual sources: the IF filter I obtained from a junked receiver and similar filters can be found without too much trouble. The LH0033 buffer had been purchased many years ago for another project and other amplifiers can be substituted, particularly high-speed video amplifiers. The main considerations are noise figure and signal handling capability. Discreet component designs can also be used and the references given provide several options.

The relays used for filter selection and the attenuator are small signal type relays obtained from Altronics, catalogue number S4130. Other relays can be used if required.

The Atmel AT90S8535 micro-controller is available from Dick Smith Electronics, catalogue number Z9205.

The Analog Devices AD9835 DDS is available from Farnell, catalogue number 334-3042.

The rest of the parts are readily available. As none of the remaining parts is very specialised, substitutions are possible and higher receiver performance may result if wise substitutions are made. It's all about experimenting!

Conclusion

The design of a receiver using a number of uncommon techniques has been presented, the receiver offers very reasonable performance and the design should be readily duplicated by an advanced experimenter. The references cited give a good overview of the techniques and make interesting reading.

I hope that the ideas presented in this article might encourage others to attempt such projects. I would be more than happy to hear from other experimenters who are trying similar ideas.

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